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WATER QUALITY CONTROL STUDY TOCKS
ISLAND RESERVOIR DELAWARE RIVER BASIN

Federal Water Pollution Control Administration
New York, New York

June 1966

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**WATER QUALITY CONTROL STUDY
TOCKS ISLAND RESERVOIR
DELAWARE RIVER BASIN**



NATIONAL TECHNICAL
INFORMATION SERVICE

**DEPARTMENT OF THE INTERIOR
FEDERAL WATER POLLUTION CONTROL ADMINISTRATION
NEW YORK, NEW YORK**

JUNE 1966

WATER QUALITY CONTROL STUDY

TOCKS ISLAND RESERVOIR

DELAWARE RIVER BASIN

A study has been made that revealed a need for storage for stream flow regulation for chloride control in the Delaware Estuary. This conclusion was based on water quality requirements, and population and industrial growth projections.

DEPARTMENT OF THE INTERIOR

FEDERAL WATER POLLUTION CONTROL ADMINISTRATION

New York, New York

for

DEPARTMENT OF THE ARMY

U. S. Army Engineer District, Philadelphia, Pennsylvania

June 1966

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I. INTRODUCTION

I-1

Request and Authority

This study was requested by the District Engineer, U. S. Army Engineer District, Philadelphia, Pennsylvania, by letter dated April 8, 1964. The letter requested that the Public Health Service review and update the recommendations for the development of water supply and flow regulation for water quality control from the proposed Tocks Island Reservoir as presented in the Delaware River Basin Report (1).

Authority to conduct the study for streamflow regulation for water quality control is provided by the Federal Water Pollution Control Act, as amended (33 USC 466 et seq.). The water supply review was performed under the provisions of the Memorandum of Agreement, dated November 4, 1958, between the Department of the Army and the Department of Health, Education, and Welfare relative to Title III of P. L. 500, 85th Congress, as amended by P. L. 87-88.

Purpose and Scope

The purposes of this study are to determine the need for water quality control from year 1960 to 2010, to set forth the locations at which flow regulation should be considered, to estimate the draft on storage that would be needed for water quality control, to identify the beneficiaries, and to estimate the benefits attributable to possible inclusion of storage in the proposed Tocks Island reservoir and other Delaware River Basin Projects to meet these demands. It is the responsibility of the Corps of Engineers to determine for what uses storage is actually provided in the Tocks Island Reservoir.

Studies conducted for this water quality control study were limited to the Delaware River and Estuary from Liston Point to the proposed Tocks Island reservoir, within ten miles of each side of the water course. For the economic study, the area investigated was defined as those counties adjacent to the Delaware River and Estuary for the same reach. The Delaware River Basin encompasses area in the four states of Pennsylvania, New Jersey, New York and Delaware.

The water supply needs set forth in the Delaware River Basin Report (1) were reviewed on the basis of current information. This review showed that conditions have not changed materially; hence, revision of the recommendations for development of water supply does not appear warranted at this time.

Acknowledgments

Information and cooperation from the following are gratefully recognized:

U. S. Army Corps of Engineers, Philadelphia District
U. S. Geological Survey
Delaware River Basin Commission
Pennsylvania Department of Health
New Jersey Department of Health
Delaware Water Pollution Commission
City of Philadelphia
Chester Water Authority
Ionics Incorporated

II. SUMMARY OF FINDINGS AND CONCLUSIONS

II-1

Findings

1. The Corps of Engineers has been authorized to construct Tocks Island multipurpose reservoir, the second of eight Federal multipurpose reservoirs, proposed for development in the Delaware River Basin for flood control, power, recreation, fish and wildlife and water quality control. It is the only reservoir proposed on the Delaware River.
2. The economic study area consists of fifteen counties adjacent to the river and estuary in the Delaware River Basin in three states: Pennsylvania, New Jersey and Delaware. The 1960 fifteen county population was 4,664,875 of which 2,002,512 people resided in the City of Philadelphia, Pennsylvania.
3. Major municipal waste sources are Trenton and Camden, New Jersey, Philadelphia and Chester, Pennsylvania, and Wilmington, Delaware. These communities discharge approximately 543,000 lb/day of first stage BOD. The major industrial wastes are from petroleum refineries, paper mills, steel mills, chemical plants and power plants. These industries and others contribute 375,000 lb/day of first stage BOD. Most of these waste sources are on the Delaware Estuary and are practicing primary treatment with a few plants providing secondary (85% BOD removal) or equivalent treatment.
4. From Trenton, New Jersey to northern Philadelphia the estuary is used for municipal water supply after extensive treatment. Downstream from Philadelphia to the Delaware-Pennsylvania state line the water is degraded appreciably by wastes from cities, industries, and runoff, especially during periods of low flow and high temperature. Below Wilmington, Delaware the water quality improves, except for the chloride concentration which is generally in excess of 250 mg/l and increases as the Delaware Bay is approached.
5. The chloride concentration in the Delaware Estuary varies inversely as the total fresh water inflow to the Delaware Estuary.
6. At times the water of the Delaware Estuary at Chester, Pennsylvania, exceeds the 250 mg/l chloride level recommended in the U. S. Public Health Service Drinking Water Standards as the upper level for municipal supplies. Consequently, in 1951 Chester abandoned the Delaware Estuary as its water supply source.

7. As fresh water inflow to the Delaware Estuary increases the dissolved oxygen concentration increases in the upper reaches but decreases in the lower reaches. The increase in the DO in the upper estuary is a result of dilution and transport of a greater portion of the waste downstream. DO decreases in the lower estuary are due primarily to the increased amount of oxygen demanding waste and the transport of lower DO water from upstream.

Conclusions

1. The economic study area population is expected to increase to 9,800,000 in year 2010.

2. Projections of population and economic growth to the year 2010 indicated that no additional storage is required for water quality control for the Delaware River between the proposed Tocks Island Reservoir and Trenton, New Jersey. This is based on the provision of secondary treatment or its equivalent at all municipalities and industries. If they do not increase their present treatment level, the resulting water quality may not meet desired water quality objectives.

3. The estimated 2010 water supply demand for the Chester Water Authority service area is 74 mgd. The Authority estimates that the present supply is sufficient to meet the projected 1970 demand. Implementation of present plans will increase the safe yield of Chester's water supply sources to meet their estimated 1990 demand.

It is estimated that the industrial firms located along the Delaware Estuary in the reach subject to seasonally high chlorides will have a 2010 water use of 3300 mgd.

4. To provide water users in the Chester-Gloucester county area with Delaware Estuary water with less than the 250 mg/l of chlorides is estimated to require a combined minimum flow of 6200 cfs in the Delaware and Schuylkill Rivers. If the estuary channel is deepened to 50 feet and widened to 1200 feet, as proposed by the Corps of Engineers, it is estimated that a flow of 6800 cfs will be needed to maintain the same chloride level.

5. Regulated flows from eight proposed Corps of Engineers multipurpose reservoirs plus flow from unregulated areas will result in a minimum combined Schuylkill and Delaware Rivers flow of 4044 cfs. To maintain a flow of 6200 cfs through 24 out of 25 years is estimated to require an additional annual draft on storage of 642,000 acre feet.

6. The most economically feasible method for dissolved oxygen control in the Delaware Estuary is being sought by the Delaware Estuary Study. The waste treatment cost has been found to vary with the DO goal and the flow. For low DO goals the cost decreases with an increase in flow, for intermediate DO goals the cost increases with an increase in flow, and for high DO goals, there is apparently no change with flow. On setting a DO goal for the estuary, the positive or negative benefits from flow regulation may be estimated.

7. Total benefits for chloride control that may be realized from flow regulation are summarized in Table II-1. These benefits apply for a 50-year period, 1960-2010.

TABLE II-1
TOTAL CHLORIDE BENEFITS

Expected Delaware and Schuylkill Rivers Flow	Cumulative Benefits			Incremental Benefit
	Industrial	Municipal	Total	
	\$/year	\$/year	\$/year	\$/year
CFS				
6200	6,060,000	73,500	6,133,500	2,173,500*
4044	3,960,000	None	3,960,000	-

*Incremental benefit directly attributable to quality control storage.

8. The benefits directly attributable to incremental quality control storage of providing 6200 cfs instead of 4044 cfs is \$2,173,500 per year.

9. The benefits realized from chloride quality control will extend throughout the Delaware Estuary although major improvements will occur in the Chester, Camden, and Philadelphia area. Water quality will also be enhanced downstream from the proposed reservoir. Consequently, these benefits are considered widespread and general in nature.

10. To insure a minimum DO of 5.0 mg/l or greater in the Delaware River, the reservoir site should be cleared, multiple level intakes should be provided at the dam, and automatic water quality monitoring instrumentation should be provided above, within the reservoir area, and below the reservoir.

III. PROJECT DESCRIPTION

III-1

Location

The proposed site of the Tocks Island dam is located on the Delaware River about five miles upstream from the renowned Delaware Water Gap and some seven miles northeast of Stroudsburg, Pennsylvania (see figure IX-1). The dam will form a 39 mile lake on the mainstem of the Delaware River. The lake will have a maximum width of about 1-1/2 miles. The immediate area surrounding the reservoir has been designated as the Delaware Water Gap National Recreational Area.

Streamflow

An area of approximately 3,827 square miles, including 915 square miles which contribute to Neversink, Papacton, and Cannonsville-New York City reservoirs, will drain to the proposed Tocks Island Reservoir. According to a 1954 U. S. Supreme Court Decree, after the Cannonsville reservoir is operational (about 1966), the City of New York will be (a) allowed to divert 800 mgd out of the basin for its water supply, and (b) required to make releases from its reservoirs so as to maintain a rate of flow of 1750 cfs at Montague, New Jersey.

The mean annual rate of flow of the Delaware River at Montague, New Jersey, based on the 25 year period from 1939 to 1964, is 6080 cfs. This annual rate of flow will be reduced by the diversion of water to New York City and New Jersey with the operation of the Cannonsville reservoir and anticipated diversions by New Jersey.

Water Quality

The waters of the Delaware River Basin above the Tocks Island Reservoir site are generally of high quality. The water is saturated with dissolved oxygen, and is low in hardness and turbidity. Information on water quality at Port Jervis, New York, is presented in Table V-3. Water quality in the streams tributary to the proposed reservoir will be comparable to the water quality of the Delaware River at Port Jervis, New York, as indicated by data from Hale Eddy and Fishs Eddy, shown in Table V-3.

Proposed Development Plan for Delaware River Basin

The Corps of Engineers, in cooperation with all interested Federal agencies, prepared a plan for coordinated long range development of the water resources of the Delaware River Basin. This plan was

published as the Delaware River Basin Report (1) in 1960. Nineteen major developments were proposed to satisfy the water resources needs in the Delaware River Basin through the year 2010. Eleven of these major multiple-purpose impoundments were scheduled for development before the year 2010. These include six new federal reservoirs, enlargement of one, and modification of another Federal reservoir. The remaining impoundments will be developed when the demand develops. The projects as planned do not provide storage for flow augmentation.

The multiple purpose Tocks Island reservoir is the only one proposed for construction on the mainstem of the Delaware River. It is also the largest impoundment proposed for the basin. Some physical data on the proposed reservoir are presented in Table III-1.

TABLE III-1
PROPOSED RESERVOIR PHYSICAL DATA*

	<u>Elevation Above Sea Level Feet</u>	<u>Surface Area Acres</u>	<u>Storage Acre Feet</u>
Stream bed	296		
Inactive long-term storage	356	3,300	80,000
Long-term (Water Supply, Power, Recreational) storage	410	11,000	410,000
Short-term (Flood Control) storage	428	16,000	275,000

*Source - Delaware River Basin Report

Location and Boundaries

The Delaware River Basin includes area in the four states of New York, Pennsylvania, New Jersey, and Delaware, as shown on Figure IX-1. The Delaware Estuary forms the Delaware-New Jersey state line from the mouth of the Delaware Bay, mile 0.0 to mile 78.7 and the Pennsylvania-New Jersey state line to mile 134.5. From mile 134.5 to mile 253.6 the Delaware River is the Pennsylvania-New Jersey state line. The river is the Pennsylvania-New York state line from mile 253.6 to the confluence of the East Branch Delaware River and West Branch Delaware River, mile 330.7.

The part of the Delaware River Basin considered for water quality control is defined as the area within ten miles on each side of the Delaware River and Estuary, hereafter referred to as the mainstem. For this report the mainstem is considered to extend from Liston Point (Tower) in Delaware to Port Jervis, New York, about 207 miles.

For this report the Delaware River and Estuary have been divided into three sections on the basis of the effects of wastes therefrom on water quality. Section 1 is that reach of the river from the confluence of the East and West Branch Delaware River to the Tocks Island Reservoir site. This section will be tributary to the proposed Tocks Island Reservoir. Section 2 is defined as the reach from the reservoir site to Trenton, N. J.; Section 3 is that segment of the Delaware River from Trenton, N. J., to Liston Point in Delaware which is subjected to the oscillating motion of the tides. Sections 2 and 3 comprise that segment of the mainstem that has been investigated for water quality control in this report. It should be noted that these sections are not identical to the river zones established by the Delaware River Basin Commission.

Geography and Topography

The headwaters of the Delaware River are in the Appalachian Plateau province and drain the western slopes of the Catskill Mountains of New York State. These mountains have a few peaks approximately 4,000 feet above sea level, though most are in the 2,500 - 3,500 feet range. Exposed rock in this part of the basin is coarse hard sandstone that does not normally dissolve or erode. The area was glaciated several times and is spotted with many lakes and swamps. Generally, the upper basin is heavily forested, and is renowned as a recreational area and as a source for water supply.

From Port Jervis, New York, to Easton, Pennsylvania, the river cuts through the Valley and Ridge province. Here the sedimentary rocks are metamorphosed and folded. Generally, the river runs parallel to Kittatiny Mountain Ridge until it cuts through the ridge at the Delaware Water Gap.

From Easton, Pennsylvania, to Trenton, New Jersey, the river cuts through the Reading Prong of the New England and Piedmont provinces. The dividing line between the Piedmont and Coastal Plain provinces is known as the Fall Line and is characterized by the change from Triassic rocks (shale, sandstone, limestone, etc.) in the Piedmont province to unconsolidated sedimentary deposits of the Coastal Plain province. The area along the Delaware Estuary from Trenton, New Jersey, to Wilmington, Delaware, is the outcrop of the Raritan-Magothy aquifer which is recharged from the fresh water reaches of the upper Delaware Estuary.

The Coastal Plain province, in southern New Jersey, is spotted with swamps and rolling hills.

Climate

The climate of the Delaware River Basin is generally mild. Average annual precipitation in the basin ranges from 45 inches per year in Port Jervis, New York, to 42 inches per year in the Wilmington, Delaware area, with maximum precipitation of 60 inches occurring at the headwaters of the East Branch Delaware River. The high precipitation is due, in part, to annual snow fall precipitation of 60-70 inches and to storms that move across the basin from a south-southwest to a north-northeast direction. The moisture-laden winds are deflected by the mountains, thereby causing more precipitation in the upper basins.

Mean air temperature ranges from 50°F at Port Jervis, N. Y., to 54°F at Wilmington, Delaware.

High runoff generally occurs in March and April primarily because of the melting of accumulated snowfall resulting from below freezing air temperatures through most of the winter. Runoff is generally at a minimum in August and September; however, the greatest precipitation occurs during the summer.

Principal Communities and Industries

The principal cities in Section 2 are Easton, Pennsylvania, and Phillipsburg, New Jersey. These two cities are located at the confluence of the Lehigh and Delaware Rivers. Paper manufacture is the

major industry with several plants in the area. Above Easton the basin is sparsely populated with most communities being agriculturally or recreationally oriented.

The major cities in Section 3 are located along the upper 86 miles of the estuary. These population centers are Trenton, Philadelphia, Camden, Chester and Wilmington. Collectively, these cities represent one of the most populated areas in the country. The five significant water-using industries in the estuary area are: petroleum refining, chemical and allied products, primary metals, paper and allied products, and electric utilities. These and other water-using industries are distributed on both sides of the estuary from Trenton to Wilmington.

Water Resources Studies

Delaware Estuary Comprehensive Study (DECS)

In late 1961 the Division of Water Supply and Pollution Control of the U. S. Public Health Service initiated the Delaware Estuary Comprehensive Study. The Study was requested by the basin states, the Interstate Commission on the Delaware River (INCODEL) (Delaware River Basin Commission Predecessor), and the City of Philadelphia, all of whom desired an intensive study of the area in which water quality was most critical. They wished to know the cause-effect relationship between pollution and water quality in the estuary, and the economic relationship between water use, waste treatment, and possible levels of water quality control. The study is concerned with the Delaware Estuary from Trenton, New Jersey, to Liston Point.

The Delaware Estuary Comprehensive Study is developing techniques for the appraisal of the water quality of the estuary. These techniques involve technical procedures to forecast the effects of stream flow and waste loads on estuarine water quality on both a short-term and a long-term basis. It is the purpose of the Delaware Estuary Comprehensive Study to apply these techniques to comprehensive water pollution control in cooperation with other agencies, and to provide a meaningful evaluation of the present and future steps which might be taken to result in an optimum level of quality in the estuary.

The technical procedures of forecasting estuarine water quality involved the development of mathematical models that involve many repetative calculations requiring high speed computers for effective application. These are general models which may be adapted to any one of several water quality parameters, such as dissolved oxygen, chlorides and turbidity.

In cooperation with the various Federal, State, interstate and local agencies involved, the Public Health Service's Delaware Estuary Comprehensive Study will develop a dynamic water pollution control plan for the foreseeable future which will be sufficiently flexible to adapt to actual development, and consistent with both the economic environment and the desires of the people of the area. The study is scheduled for completion in 1967.

The Tocks Island study has made use of the water quality models, developed by the DECS. In addition, it has utilized data from the municipal-industrial waste and water use inventory and water quality sampling program of the DECS.

Delaware River Basin Commission (DRBC)

The Delaware River Basin Commission was formed by the Delaware River Basin compact (2) in 1961. Members of the Commission are the Governors of the states of Delaware, New Jersey, New York, and the Commonwealth of Pennsylvania, and the Secretary of Interior. The compact, in part, empowers the Commission to control the water resources of the Delaware River Basin, establish standards for waste treatment, approve any project having a substantial effect on the water resources of the basin, and formulate and approve a comprehensive plan for the immediate and long range development and uses of the water resources of the basin. This report has been discussed with the Commission in the course of its preparation.

Flow Rates

Above Trenton, N. J., the Delaware River is gaged at five stations by the U. S. Geological Survey (USGS) (3). Pertinent streamflow data for these gaging stations through water year 1964 are summarized in Table V-1.

The Port Jervis station reflects the flows that will be tributary to the proposed Tocks Island Reservoir. At Montague, New Jersey, the U. S. Supreme Court requires that releases from the City of New York Reservoirs "...shall be in quantities designed to maintain a minimum basic rate of flow at the gaging station of the United States Geological Survey (U.S.G.S.) at Montague of 1525 c.f.s. (985.6 mgd) until the Cannonsville project is completed and its reservoirs first filled to the extent that 50 billion gallons above the lowest outlet are available for diversion and releases, and 1750 c.f.s. (1131.1 m.g.d.) thereafter."

The Belvidere and Riegelsville stations show the flow above and below the confluence of the Lehigh and Delaware Rivers, respectively. The Trenton station gages the flow entering the estuary from the Delaware River.

TABLE V-1

V-3

SUMMARY OF FLOWS*
DELAWARE RIVER

Station	Miles Above Mouth of Bay	Years of Record	Drainage Area Square Miles	Flow - cfs		
				Maximum daily	Minimum daily	Mean Annual
Trenton, N.J.	134.5	52	6,780	329,000	1,220	11,680
Riegelsville, N.J.	174.8	58	6,328	340,000	870	11,070
Belvidere, N.J.	197.7	42	4,535	273,000	609	7,983
Montague, N.J.	246.3	24	3,480	250,000	412	6,080
Port Jervis, N.Y.	254.7	60	3,076	233,000	175	5,537

*Source - Surface Water Records of New Jersey. Flows at Trenton are unadjusted for diversions above station.

Table V-2 summarizes the seven and thirty consecutive day mean low flows of the Delaware River for selected recurrence intervals at Trenton and Riegelsville. These flows reflect 57 years of record at Riegelsville and 53 years of record at Trenton through climatic year 1965. The flows in this table were used in the computations for the critical dissolved oxygen concentration for the Delaware River.

TABLE V-2

FREQUENCY OF OCCURRENCE OF 7- AND 30-DAY LOW FLOWS*
DELAWARE RIVER

Recurrence Interval (Years)	Minimum Average Flow, CFS			
	Trenton		Riegelsville	
	7 day	30 day	7 day	30 day
50	1300	1540	1020	1190
25	1350	1600	1180	1350
20	1380	1620	1210	1400
10	1480	1700	1350	1550
5	1600	1850	1510	1780

*Source - Data generated by Public Health Service

Below Trenton the Delaware River is tidal. The largest tributary to the estuary below Trenton is the Schuylkill River. From the confluence of the Schuylkill and Delaware Rivers to Fairmount Dam (8.2 miles), the Schuylkill River is tidal. At times the instantaneous flow over the dam is zero. Average rate of flow for 33 years (1931 to 1964) is 2,900 cfs. However, this does not include an average diversion of 278 cfs (180 mgd) above the station by the City of Philadelphia for municipal water supply. The minimum and maximum daily flow observed at the gaging station is 7 cfs and 135,000 cfs, respectively.

Water Quality

Delaware River - Section 1

The Delaware River water quality in this section has been investigated by the U. S. Geological Survey (4) and the New York State Department of Health (5). Generally the waters of the river and its tributaries for this section are of excellent quality. The dissolved oxygen concentration ranges from 8 to 10 mg/l during the summer period. For the New York State portion of the basin, hardness and dissolved solids average approximately 22 and 37 mg/l, respectively.

At Port Jervis for the 1958 and 1959 water years the hardness, dissolved solids, and nitrate (NO_3) concentrations averaged 26, 45 and 1.2 mg/l, respectively. The suspended sediment load was approximately 4,300 tons/day. The USGS reports that 98% of the time the suspended sediment load was less than 5,000 tons/day and averaged only 160 tons per day. However, during their study, over 400,000 tons of suspended sediment was discharged at Port Jervis by the Delaware River during one 18 day period.

Seasonal variations in water quality in Section 1 can be expected to be reduced when the Cannonsville Reservoir is placed in operation. The effect of the reservoir in retaining water will permit the mixing of water of varying quality and result in the release of water of more uniform quality. In addition, suspended sediment will settle in the reservoir, thereby improving one aspect of the physical water quality.

The mean values of a number of water quality constituents of the West Branch Delaware River at Hale Eddy, New York; East Branch Delaware River at Fishs Eddy, New York; and Delaware River at Port Jervis, New York, for the 1958 and 1959 water years, are tabulated in Table V-3.

TABLE V-3
 WATER QUALITY*
 DELAWARE RIVER - SECTION 1
 1958 & 1959 Water Years

Constituent	Hale Eddy, N.Y.	Fishes Eddy, N.Y.	Port Jervis, N.Y.
Mean concentrations in mg/l, except as noted			
Temperature - °C	10.6	8.9	11.0
Silica	3.0	2.2	5.0
Iron	0.07	0.06	0.06
Calcium	7.4	6.1	7.1
Magnesium	1.8	1.0	1.6
Sodium	3.0	1.5	2.4
Potassium	1.2	0.6	1.0
Bicarbonate	20	12	20
Sulfates	10	9.2	10
Chlorides	4.2	2.8	3.0
Fluorides	0.1	0.1	0.1
Nitrate (NO ₃)	1.8	1.5	1.2
Dissolved Solids	45	33	45
Hardness			
Calcium & Magnesium	26	20	26
Noncarbonate	10	10	10
Specific conductance (micromhos at 25°C)	74	52	65
pH - range	6.1-7.5	5.8-7.1	6.3-7.2
Color - units	4	4	4
Suspended-sediment Tons/day	-	-	4,305

*Source - U. S. Geological Survey

Delaware River - Section 2

Water quality data for the Delaware River below Port Jervis, New York, are available from studies made by the U. S. Public Health Service, INCODEL and the City of Philadelphia. The data were collected sporadically from 1957 through 1964. Results of the analyses from some of these studies are presented in Table V-4.

Below Port Jervis, N. Y., the river water is generally of high quality. In normal flow years, it is saturated with dissolved oxygen. During periods of extreme low flows and high temperatures, the minimum dissolved oxygen concentrations of approximately 70% of saturation have been observed. Minimum DO concentrations generally occur below the confluence of the Lehigh with the Delaware River. These low dissolved oxygen concentrations are mainly attributed to the waste loads transported by the Lehigh River and partially treated industrial wastes discharged to the Delaware River in the Easton-Phillipsburg area. All municipal water pollution control plants from Port Jervis downstream to Trenton (excluding the Lehigh River Basin) are designed and operated to provide for secondary treatment obtaining at least 85% removal of organic matter.

The Delaware River at Trenton, New Jersey, for approximately 1 mile above the head of the tidewater passes over a series of rock ledges known as Trenton Falls. In this reach of the river the water is well aerated and it enters the estuary nearly saturated with dissolved oxygen.

TABLE V-4

V-7

WATER QUALITY
DELAWARE RIVER - SECTION 2

Constituent	Montague, N.J. April- Dec., 1961*	Delaware River @ Martins Creek Oct., 1962- Sept., 1963**	Riegelsville, N.J. April - Dec., 1961*	Trenton, N.J. July, 1963- June, 1964***
Mean concentrations in mg/l, except as noted				
Temperature - °C	16.7	11.9	18.5	13.6
Dissolved Oxygen	9.2 5.7 Min.	10.2 6.9 Min.	8.6 5.2 Min.	11.8 8.1 Min.
Biochemical Oxygen Demand	-	1.1	-	2.6
Chemical Oxygen Demand	-	14	-	-
pH - (range)	6.3-9.7	6.8-8.0	7.2-9.2	6.3-9.2
Sulfates	-	11	-	-
Chlorides	-	4	-	-
Phosphates	-	0.1	-	0.2
Nitrites (N)	-	-	-	0.03
Nitrates (N)	-	-	-	0.7
Dissolved Solids	-	54	-	-
Hardness				
Calcium & Magnesium	-	28	-	63
Non-carbonate	-	9	-	35
Color - units	-	14	-	-
Turbidity - units	9.2	-	8.0	7
Specific Conductance (micromhos)	-	-	-	146
- No data				

*Interstate Committee on the Delaware River

**Source - PHS National Water Quality Network

***Source - Delaware River Estuary Comprehensive Project

Delaware Estuary - Section 3

The water quality of the Delaware Estuary and its tributaries has been investigated by the DECS-FWPCA, USGS, the City of Philadelphia, and other interested water quality control agencies. Water quality data procured by DECS and the City of Philadelphia for the period July - September, 1964, have been averaged and are presented in Table V-5. These data are typical of drought summer low flood conditions. Data for other periods are available at the DECS office through the FWPCA Storage and Retrieval System (STORET).

From Trenton to Philadelphia the Delaware Estuary is of marginal quality. Chlorides are generally below 30 mg/l, dissolved oxygen is usually above 4 mg/l, turbidity averages about 10 units, and coliforms are below 5000/100 ml. This reach of the estuary is used for water supply; however, complete treatment, including extensive taste and odor control, is necessary to make the water potable.

Below Philadelphia the water is of poor quality during the summer months when the water temperature is high and especially when the flows are low. During periods of high temperature and low flow about twenty miles of the estuary are practically devoid of dissolved oxygen indicating that at times sections of the estuary have septic conditions. Synthetic detergent (ABS) and phenol are above the limit recommended in the U. S. Public Health Service (11) Drinking Water Standards. However, ABS has been replaced by LAS, a biodegradable detergent which is removed by conventional waste treatment practices.

Table V-5 shows the mean chloride concentration of the Delaware Estuary for two periods, July - September and September - November, 1964. These data show that the chloride concentration is higher for the latter period. For September - November, 1964, the average ranged from 11 mg/l at Trenton to 4700 mg/l below Wilmington.

TABLE V-5

AVERAGE WATER QUALITY
DELAWARE ESTUARY

Station	River Miles Above Mouth	Water Temp. °C	July Through September, 1964				pH	Turb. Units	M.F. Col. #/100 ml(a)	Phenol mg/l	Synthetic Detergent (ABS)mg/l
			Chlorides mg/l	Diss. Oxy. mg/l	BOD mg/l	(b)					
Trenton, N.J.**	134	25.8	7	11	10.3	3.1	8.6	8	510	-	-
Fieldsboro, N.J.*	127	27.4	11	14	6.7	2.6	7.6	9	850	0.01	0.19
Burlington, N.J.*	118	26.7	14	16	5.2	2.8	7.3	10	620	0.00	0.19
Torresdale, Pa.*	111	26.6	16	21	6.4	2.8	7.3	10	3,200	0.01	0.24
Palmyra, N.J.*	107	26.6	22	39	4.7	2.7	7.2	10	21,000	0.01	0.30
Ben. Frank. Br.*	100	26.3	44	113	1.3	4.4	6.9	12	62,000	0.03	0.50
Navy Yard*	93	26.0	83	241	0.7	4.3	6.9	13	68,000	0.02	0.58
Eddystone, Pa.*	84	25.8	282	760	1.0	5.2	6.7	16	16,000	0.03	0.59
Marcus Hook, Pa.**	79	25.5	492	1150	1.7	5.1	6.4	23	25,000	0.04	0.53
Del. Mem. Br.**	69	24.9	1692	2600	4.5	2.4	6.3	24	9,100	-	-
Reedy Isl., Del.**	55	24.2	3569	4700	7.2	2.7	7.1	20	880	-	-

-No Data

*From City of Philadelphia

**From FWPCA-DECS

(a) Geometric Mean

(b) September-November, 1964

Water quality of the Delaware River depends, in part, on the quality of waste discharged to the river and its tributaries. The waste loads discharged are related to the future population of the area and the accompanying industrial activity.

Increases in population may be expected to result in increases in wastes discharged to the river, modified of course, by legal and social changes of the area. Practices in water use such as increases in the automatic water using appliances, metered services, will influence future waste discharges. Legal requirements such as mandatory separation of storm and sanitary sewer lines, more stringent effluent standards, will also affect the amount of waste that will reach the river.

The projected economy from base year 1955 for the Delaware River Basin is presented in the Delaware River Basin Report (1). This work was prepared by the U. S. Department of Commerce, Office of Business Economics (OBE).

Water quality control requirements were determined from municipal and industrial waste loads which were based on the anticipated economic development of the study area. The projected municipal and industrial waste loads, in general, were based on the economic base study made by the Office of Business Economics for the Corps of Engineers (1). For the economic investigation the study area was defined as those counties in Pennsylvania, New Jersey and Delaware bordering Sections 2 and 3 of the Delaware River and Estuary.

Past and Present

The total population of the study area has increased about 33% from 3,426,710 in 1940 to 4,875,484 in 1960. Population centers such as Philadelphia appear to have reached a stable population density. This is indicated by a slight decrease in population in Philadelphia from 1950 to 1960. However, high rise apartments may change this trend in the future. Major increases have taken place in counties adjacent to Philadelphia county. Table VI-1 shows the U. S. Census of Population (6) by county for the economic study area of the basin.

The major water using industries in the basin are petroleum refining, paper and allied products, primary metals, chemical and allied products and electric utilities. There are several reasons

why these industries are located in the Delaware River Basin or why new industry may want to consider the Basin for a plant site. Three major considerations are availability of 1) present and future markets, 2) large areas of land for plant location, and 3) ocean vessel navigation on the estuary.

TABLE VI-1
PAST STUDY AREA POPULATION

State County	1940	1950	1960
Pennsylvania			
Pike	7,452	8,425	9,158
Monroe	29,802	33,773	39,567
Northampton	168,959	185,243	201,412
Bucks	107,715	144,620	308,567
Philadelphia	1,931,334	2,071,605	2,002,512
Delaware	310,756	414,234	553,154
New Jersey			
Sussex	29,632	34,423	49,255
Warren	50,181	54,374	63,220
Hunterdon	36,766	42,736	54,107
Mercer	107,318	229,781	266,392
Burlington	97,013	135,910	224,499
Camden	255,727	300,743	392,035
Gloucester	72,219	91,727	134,840
Salem	42,274	49,508	58,711
Delaware			
New Castle	179,562	218,879	307,446
TOTAL	3,426,710	4,015,981	4,664,875

The present industrial load has been determined from inventories by the State Health Departments and DECS; supplemented by the waste sampling program by the DECS. Although the latter has not been completed, preliminary results presently available have been used in this study.

Future

Population projections made by the Office of Business Economics (1), Penn Jersey Transportation Study (7) and Temple University (8) were reviewed. The population growth is anticipated to be primarily caused by an excess of births over deaths. The net effect of migration, the excess of in-migrants over out-migrants, is anticipated to be of much smaller consequence than that of natural increase. Error in the assumed rate of migration by OBE will therefore not alter the population projections significantly.

The Office of Business Economics population projections were made for several large service areas using the component method of analysis. The appropriate service area growth rates were applied to each of the 15 counties in the economic study area. These results indicate an expected population increase from 4,664,875 in 1960 to 6,740,000 in 1980 and 9,840,000 in 2010. The main portion of this growth is anticipated to be along the estuary from Trenton to Wilmington inclusive, with the Wilmington area excelling all areas in rate of growth. Past (1960) and future (1980 and 2010) populations for the economic study are presented by states in Table VI-2.

TABLE VI-2

PAST AND FUTURE STUDY AREA POPULATION*

Economic Study Area	1960	1980	2010
Pennsylvania	3,114,370	4,310,000	5,880,000
New Jersey	1,243,059	1,720,000	2,500,000
Delaware	307,446	710,000	1,460,000
TOTAL	4,664,875	6,740,000	9,840,000

*Source - Delaware River Basin Report

Industrial water use and waste load projections were made by the PHS using employment projections as presented in the Delaware River Basin Report (1). These employment projections were made by major industry groups. Table VI-3 shows these projections for 1965, 1980 and 2010.

These projections were developed on the basis of anticipated national growth as modified by differential growth rates of industry groups in the Delaware River Basin.

TABLE VI-3

DELAWARE RIVER SERVICE AREA*

EMPLOYMENT PROJECTIONS BY INDUSTRIES, 1965-2010

(Thousands)

	1965	1980	2010
All Industries	10,300	12,400	18,000
Commodity producing industries, total	4,200	5,100	7,400
Manufacturing, total	3,390	4,210	6,100
Food & kindred products	230	270	400
Chemicals & allied products	235	325	630
Petroleum & coal products	75	90	145
Primary metal industries	180	240	400
Paper & allied products	100	150	300
Non commodity producing industries, total	6,100	7,300	10,600

*The Delaware River Service Area as defined in the Delaware River Basin Report (1) includes 49 counties in the Delaware River Basin and other relatively nearby counties which are either present or potential users of the Delaware River Waters.

Future growth for the principal industries will depend, in large part, on the increase of the local market and on a decrease in the unit cost of transportation of raw materials. One way of accomplishing this is by greater utilization of the capacity of existing ocean vessels through the deepening of the channel of the Delaware Estuary. An increase in the petroleum industry will be accompanied by a related increase in the chemical industry, principally in the petrochemicals, because of the availability of raw materials.

The steel industry in the basin should enjoy growth because of its key location in the North Atlantic States, port facilities and available land at its present location. However, although the steel industry in the basin supplies the immediate area as well as surrounding regions, its share of the total U. S. market is expected to decrease. Future expansion is expected to take place at existing plants rather than through construction of new integrated mills. Technological changes may permit the industry to gradually expand capacity at their present locations and meet the future demand without the very large expenditure needed for building new integrated mills. (9)

Expansion of the paper and paper board industry in the basin is dependent on the future demand in the immediate market area. The major portion of the pulp used in the Delaware Basin is obtained from outside the basin; hence, the industries have limited themselves to serving the local market. Future expansion is expected to take place at existing plant sites (9).

Projections of population were translated into municipal waste production figures for the analysis of stream quality on the basis of a unit load of 0.25 pounds of first stage BOD per capita per day. Industrial waste loads are based on the conclusion that waste production per unit output will remain constant in the future.

Water Uses

Present Uses

The present uses of the Delaware River above Trenton are municipal water supply, industrial water supply, habitat for fish and aquatic life, recreation (sport fishing, waterfront parks, swimming), and waste-water assimilation and transport.

The use of the Delaware Estuary varies appreciably throughout its length. From Trenton to northeastern Philadelphia the estuary is used for water supply, recreation, fish and aquatic habitat life and is a recharge source for ground water supplies in adjacent coastal areas. Below Wilmington, Delaware, the estuary is used for recreation and commercial fishing. The entire length of the estuary is used for industrial water supply (cooling, process, fire protection), navigation, and waste assimilation and transport.

Future Uses

Future uses will probably include at least the present uses. Consideration for possible future upgrading of water quality for all uses is governed by the demand for improved water quality and the cost of the improvement.

Municipal, industrial, ground water recharge, recreational, navigation and waste assimilation and transport water uses are expected to increase. Commercial fishing is anticipated to continue at the present level. The anticipated water use increases are based on population growth, plans for development by the City of Philadelphia (several large waterfront recreational areas to include sport fishing and boating), expansion of navigation through provision for a deeper channel, and anticipated growth and planned expansion by existing water using industries.

Water Quality Goals

Because of the variety of water uses of the Delaware River and estuary, the quality which must be maintained to protect these uses is defined by the economically efficient use presenting the most stringent limitation. For example, the ABS concentration is limited by municipal use, dissolved oxygen levels must be maintained for fish and aquatic life use and temperature levels for industrial (cooling) use.



The quality of water needed for some of the above uses has been clearly defined, but for others, quality requirements vary considerably, and have been stated only in very general terms. For some uses, the concentration of the impurity which can be tolerated varies considerably depending on equipment installed and processes used. For others, the concentration of the impurity is not as important as the short term variation in the quality as processes cannot be modified rapidly to accommodate the changes.

Generally, the suitability of a stream for its intended uses is indicated by such water quality indicators as pH, dissolved oxygen, temperature, bacteria, and solids. Of these water quality indicators, dissolved oxygen, a significant indicator of an acceptable environment for fish and other aquatic life, was selected to determine the effects of organic waste loads from natural, industrial, and municipal sources. Also, maintenance of an acceptable dissolved oxygen concentration generally assures an adequate quality of water for other water uses. For example, water saturated with DO is usually low in suspended solids; however, high DO is not related to hardness and chloride concentration.

Delaware River - Section 2

For the mainstem of the Delaware River above Trenton, New Jersey, the DRBC requires that waste discharges "...shall be sufficiently free of turbidity that it will not cause noticeable turbidity in the water of the Delaware River, ...shall show a reduction of organic substances of at least eighty-five per centum (85%) as measured by the biochemical oxygen demand, ...shall not cause a reduction of the dissolved oxygen content of such water of more than five per centum (5%)."

Tests conducted by the U. S. Public Health Service (10) have indicated that for a well-rounded warm water fish population, dissolved oxygen concentrations should not be below 5 mg/l for more than 8 hours of a 24-hour period and at no time below 3 mg/l. Considering the uses, regulations and requirements for maintaining a well-rounded warm water fish population, a dissolved oxygen goal of 5 mg/l has been selected for the Delaware River above Trenton. Maintaining this minimum dissolved oxygen concentration also assures good quality water for other water uses.

Toxic materials from industrial processes and land runoff should not be present in such quantities as to be harmful to fish and aquatic life and other uses (21).

Delaware Estuary - Section 3

Water quality goals for the Delaware Estuary are being considered as part of the work of the Delaware Estuary Comprehensive Study acting through its various advisory committees. These goals will be presented as part of the DECS report and will be used for the formulation of a comprehensive water quality improvement plan. Although the present interstate standards indicate some quality goals, it is not possible at this time to determine the appropriateness of these standards and indeed they are the subject of intensive review. Therefore, explicit water quality goals for variables that are affected by extensive waste treatment programs cannot be specified at this time. However, the effects of increased fresh water inflow on a range of feasible DO levels have been analyzed and the results are indicated below. Other water quality parameters can be expected to behave similar to DO. On the other hand, chloride concentrations are (1) a result of sea water intrusion, (2) not generally affected by water and waste treatment processes and (3) significantly affected by fresh water inflows to the estuary. The U. S. Public Health Service Drinking Water Standards (11) recommend that the chloride (Cl) concentration in a water supply should not be in excess of 250 mg/l. Chlorides are not removed by conventional water treatment practices. This has therefore been selected as the goal where the estuary is used for municipal water supply. It is also considered the upper limit for most industrial process uses without special treatment.

Sources of Waste

Municipal - Section 2

From the proposed Tocks Island Dam to Trenton, New Jersey, there are seven significant sources of municipal waste that discharge to the Delaware River or its tributaries. All seven municipalities are providing secondary treatment at this time. Two communities, Easton, Pennsylvania, and Phillipsburg, New Jersey, account for 86 per cent of the total municipal waste load. Other communities discharging municipal waste are Stroudsburg, East Stroudsburg, Bangor, and Pen Argyl, Pennsylvania, and Frenchtown and Lambertville, New Jersey. The waste load discharged from these seven plants has a Population Equivalent (PE) of 26,000. Municipal waste discharges for section 2 are presented in the Appendix.

Waste loads expected from these municipalities were based on the population projections of OBE. Based on available knowledge of the waste sources it has been concluded that the relationship of waste discharged to population will remain the same. For years

1980 and 2010, it is estimated that the treated municipal sewage discharged to the river will have a PE of 30,000 and 48,000, respectively.

Municipal - Section 3

Fifty-three municipal water pollution control plants discharge waste into the Delaware Estuary or the tidal portion of its tributaries. The first stage BOD load from these plants is approximately 576,000 lb. per day (2,300,000 PE). Eight water pollution control plants serving Trenton, Greater Philadelphia, Camden, Wilmington and Chester account for 543,000 lb. per day, or 94% of the total. Data for these eight plants are summarized in Appendix A. Additional information on these and the other plants is available from the FWPCA-DECS.

The Delaware Estuary Comprehensive Study, operating through its policy advisory and water use and technical advisory committees, has embarked on a cooperative municipal sewage effluent sampling program. Eight of the major plants are being sampled on a monthly basis. Results from this program may be obtained from the DECS as they become available.

Industrial - Section 2

The major industrial waste loads discharged to the Delaware River or its tributaries in Section 2 of the study area (from the proposed Tocks Island dam to Trenton) originate from the chemical and paper industries. These industrial waste sources are located in the Easton-Phillipsburg area. While the waste from these industries is both organic and inorganic, only the organic wastes discharged to the Delaware have been quantified. Information on industries discharging greater than or equal to 0.1 mgd of waste is presented in the appendix.

Data from New Jersey and Pennsylvania Departments of Health indicate that about 15% of these major waste sources are providing secondary treatment. These Departments of Health have determined or are in the process of determining abatement needs for each industry. To date, their results indicate that approximately 37% of these industries do not have any abatement needs.

Fourteen of the major waste sources are discharging a waste load of 60,000 lbs. per day of first stage BOD. Based on the commonly accepted factor of 0.25 lb. BOD/cap-day, this is 240,000 PE. However, this is not to imply that industrial waste is of the same character as domestic sewage.

Based on the projected industrial growth for each of these major waste sources above Trenton, N. J., it is estimated that these industries will be discharging 23,000 and 38,000 lbs. of first stage BOD (92,000 and 152,000 PE) in 1980 and 2010, respectively. Note that the 1980 and 2010 loads are lower than at present. This results from the provision of secondary treatment achieving the equivalent of at least 85% BOD removal by 1980 and thereafter, which is the basis for estimating flow regulation needs.

Industrial - Section 3

The DECS has prepared an inventory of all known industrial waste discharges to the Delaware Estuary (Section 3) and its tidal tributaries. This inventory, presented in the appendix, shows that 48 industries are discharging wastes having a volume of 0.1 mgd or more. A preliminary estimate of the waste load discharged by these industries indicates that 375,000 lb. of first stage BOD is discharged daily. On a BOD basis, this is approximately equal to a waste load from 1.5 million people.

In order to properly evaluate the present and future water quality of the estuary more precise data were necessary for many of the industrial discharges. A review of the inventory showed that a water influent and waste effluent sampling program was necessary for 23 industries. Approval to sample these industries was obtained from the State Departments of Health and plant management. Results from this sampling program are being reviewed cooperatively by the DECS, the state water pollution control agencies, and the individual industrial concerns.

For the industrial installations in Section 3, it is difficult to determine the degree of compliance with the existing waste treatment requirements. For a complex industry, the concept of per cent removal has little or no meaning. In the absence of data to the contrary, many of the plants are considered to be in administrative compliance. It is probable that when the DECS sampling program is completed, compliance with the requirements may be found to be lacking in some cases.

Tributaries - Section 2

Tributaries to the main stem of the Delaware River are considered as point sources of waste representing the net pollutional effect of all discharges upstream in the tributary. The two significant tributaries discharging appreciable quantity of waste are the Lehigh and Musconetcong Rivers. In the Delaware River

Basin Report (1) the population equivalent discharged by the Lehigh and Musconetcong Rivers are reported as 88,500 and 9,200, respectively. The Water Supply and Water Quality Control Study, Beltzville Reservoir, Lehigh River Basin (15) shows that the waste load discharged by municipalities, institutions, and industries into the Lehigh River is about 58,000 lbs. of first stage BOD. Other tributaries also contribute waste. However, due to the relatively low flows and waste concentrations in these tributaries the total waste load reaching the Delaware River is considered insignificant by comparison with other waste sources and the flow available in the Delaware River.

Tributaries - Section 3

Twenty-three streams tributary to the Delaware Estuary were sampled from July, 1963 through September, 1964 by the DECS. These streams were selected for sampling because of the possibility of high concentrations of pollutants as well as high flows. The data obtained from this tributary sampling program will be used where appropriate to estimate loadings from the tributaries in the study of the Delaware Estuary. Data from this program are presented by station in the report, "Basic Stream Quality Data, Selected Tributaries of the Delaware Estuary, Basic Data Report No. 2." This report is available from DECS.

Methodology

Significant water quality data were obtained from several stream sampling programs by DECS and other interested parties. These data define the existing water quality and are a basis for the prediction of future water quality as a function of waste removal and flow augmentation.

For Section 2, the classical Streeter Phelps DO Sag equation was utilized to evaluate the effects of waste inputs and flow regulation.

For Section 3, a mathematical model developed by the DECS has been used for describing the time variation of dissolved oxygen. This model involves the solution of differential equations describing the individual factors affecting water quality by appropriate computational schemes. All schemes require some mode of high speed computation (digital or analog computer). The details of the models are described in the literature (13, 14) and the results are utilized below in the evaluation of the effect of flow regulation on dissolved oxygen.

Inputs to these analyses include reaeration, diffusion, decay and river flow rates; municipal and industrial waste loads discharged to the estuary; and estimates of the cost of additional treatment for each of the waste inputs. Reaeration, diffusion, and decay rates cannot be measured directly, hence several combinations are being investigated so as to determine the sensitivity of the solution as a function of each parameter. Twenty-seven significant municipal and industrial waste sources have been used to date. These waste sources constitute more than about 90% of the waste load discharged into the Delaware Estuary. Additional sources of waste such as bottom deposits, combined and separate stormwater sewers, nitrification of waste in the estuary, and waste transported by tributaries to the estuary will be included in future runs. Estimates of the capital cost of facilities to remove additional waste as needed from each plant have been made by DECS staff. As more precise information becomes available from the sampling programs and from direct discussions with each waste producer the data will be utilized to improve the estimate of the effects of the various water pollution control programs and their accompanying costs. Results referred to and used herein are based on the most recent available from DECS.

A modified version of the DECS mathematical model (13) has been used to predict chloride concentrations in the Delaware Estuary for various tributary flow patterns. In general, the mathematical model was used to make chloride predictions based on fresh water inflow, chloride concentration of the Delaware Bay, and tidal diffusion. On verifying an observed profile, all parameters were held constant except fresh water inflow. Thus chloride predictions were made as a function of tributary flow to the estuary.

Effect of Flow Regulation on DO Profile

Effect of Increased River Flow - Section 2

Increased flow in the Delaware River results in dilution of the waste loads discharged and higher velocities. Since the reaeration rate varies approximately as the square root of the velocity, the increased flow results in higher reaeration rates, consequently, providing more dissolved oxygen to oxidize the organic waste. Increased velocity also results in a decrease in the transport time of waste.

The dissolved oxygen concentration for section 2 was investigated for three periods, 1963 (present), 1980, and 2010. For the present conditions, DO and BOD data collected by the City of Philadelphia, and stream physical data from the U.S.G.S. were used to

estimate the stream reaeration rate. The deoxygenation rate constant was estimated from information in the literature. With these coefficients, information on waste loads, and physical data on the stream, the resultant critical dissolved oxygen concentrations were computed. Adequate treatment, considered to be providing the equivalent of 85 per cent removal of first stage BOD, was considered to be provided in each case.

Of all the existing and projected waste loads discharged into Section 2 of the Delaware River, the most significant is the Lehigh River. The waste transported by the Lehigh River, and municipal and industrial waste discharged in the vicinity of the confluence of the Lehigh with the Delaware results in the major oxygen sag in this section.

The present and projected waste loads of the Lehigh River were estimated by the Public Health Service and are reported in the Beltzville Water Supply and Water Quality Control Study (15). These waste loads and the water resources program as presented in the Delaware River Basin Report (1) were used to compute the resultant critical dissolved oxygen concentrations.

Low flow frequency curves were available from the Delaware River Basin Report (1) for the U.S.G.S. gaging station at Trenton. Similar flow frequency curves were constructed for the U.S.G.S. gaging station at Riegelsville, New Jersey, using flow rates through climatic year 1957. Low flow frequency curves were also made for the annual average Delaware River flow through year 1964 at Trenton and Riegelsville. These curves were used for estimating the annual flow for a given per cent frequency.

The design flow selected for maintaining the dissolved oxygen goal is the one in twenty-five year seven consecutive day mean low flow of 1180 cfs at Riegelsville. Considering this flow, projected municipal and industrial waste loads in the Delaware and Lehigh River Basins and the provision of adequate waste treatment by municipalities and industries, it was determined that minimum dissolved oxygen concentration would be maintained at or above 4.0 mg/l through 2010, the end of the design period.

As stated in Chapter III, Project Description, the U. S. Supreme Court Decree requires that the minimum flow of the Delaware at Montague, N.J., will be maintained at 1750 cfs. With this flow, tributary flow, natural runoff, and ground water, it is estimated that the dissolved oxygen concentration in the river will be equal

or greater than 5.0 mg/l. Under the present plan of operation of the Tocks Island reservoir, minimum discharge from the reservoir is anticipated to be 1800 cfs. This flow and the natural flow are estimated to be sufficient to maintain a minimum dissolved oxygen of 5.0 mg/l. This assumes that reservoir releases have a DO concentration greater than 5.0 mg/l at all times.

Effect of Reservoir Operation on D.O.

The dissolved oxygen concentration of the impounded water will vary with season and is dependent upon organic wastes and nutrients entering the reservoir as well as seasonal temperature changes, wind, light, and living and decaying organisms (16). For a few weeks in the spring and fall, water temperatures are uniform and the water is homogenous from top to bottom. The impounded (lake) water circulates as a result of the uniform density and wind action and the oxygen absorbed from the atmosphere and that produced from photosynthesis is mixed throughout the water. For the major part of the year the water is stratified. During the summer three distinct layers of water eventually form: the epilimnion, thermocline, and hypolimnion.

The upper layer, the epilimnion, represents the warm region. In this layer the DO is usually abundant. Diffusion, surface water agitation and photosynthesis provide sufficient oxygen so that the concentration is generally near saturation. The middle layer, the thermocline, is a transitional layer for temperature and as a result of the density difference acts as a barrier to mixing of oxygen rich water from the epilimnion with waters in the hypolimnion. The temperature drops rapidly with depth, and photosynthesis is reduced. The lower layer, the hypolimnion, is characterized by low temperatures and low DO. Organic matter in the bottom muds, in the water, and that that settles to the bottom decomposes using oxygen. In lakes or impoundments subject to organic waste loads or nutrient enrichment this layer may become devoid of oxygen as the stratification season progresses.

To insure good quality reservoir releases for maintaining 5.0 mg/l of DO throughout section 2, the following recommendations are made:

- 1) The reservoir site should be cleared of organic matter, particularly shrubs, weeds, bog deposits, etc., to reduce the oxygen demand that results from decaying organic matter.

- 2) All wastes entering the reservoir directly or through streams should be treated.
- 3) Reservoir releases should be managed so as to provide dissolved oxygen concentration greater than 5 mg/l at all times. To assure this, multiple level intakes or other equally effective control measures should be provided at the dam to permit flexibility in operation.
- 4) Automatic water quality monitoring instrumentation should be provided above, in, and below the reservoir and at critical stream reaches downstream.
- 5) The prescribed flow of 1750 cfs at Montague (or equivalent flow below Tocks Island) should be maintained as a daily average.

Effect of Flow on DO Profile - Delaware Estuary - Section 3

A study has been made to determine the effect of flow regulation on the DO profile for the Delaware Estuary. Two flow regulation schemes were investigated: steady state flow and transient flow. These investigations indicate the direction of the effect of flow augmentation on the DO profile.

Three large analog computers were used to make the DO simulation. All variables, except tributary flow, were held constant, thus any change in the DO profile was related only to flow. The details of the program may be obtained from DECS.

Steady State Flow Augmentation

Steady state flow is a uniform fresh water inflow into the Delaware Estuary for a long period. Four steady state flows from 3000 to 12,000 cfs were used to determine the effect of steady state fresh water inflow on the summer DO profile. These flows were investigated to more fully describe the effects of fresh water inflow on the DO in the estuary. They are not to be construed as alternate flow augmentation schemes. The results from these runs are presented in figure VII-1.

From Trenton to Philadelphia increases in steady state flows resulted in increased DO. Maximum DO increases over the 3000 cfs profile were realized above Philadelphia and were about 1, 3, and 4 mg/l for the 6000, 9000, and 12,000 cfs flows, respectively. For the flows investigated the minimum DO shifted downstream from its location at a flow of 3000 cfs. The higher flows resulted in a higher minimum DO. However, below Philadelphia, the increased steady state flow resulted in an average DO decrease of about 1.0 mg/l for considerable distances downstream.

VII-9A

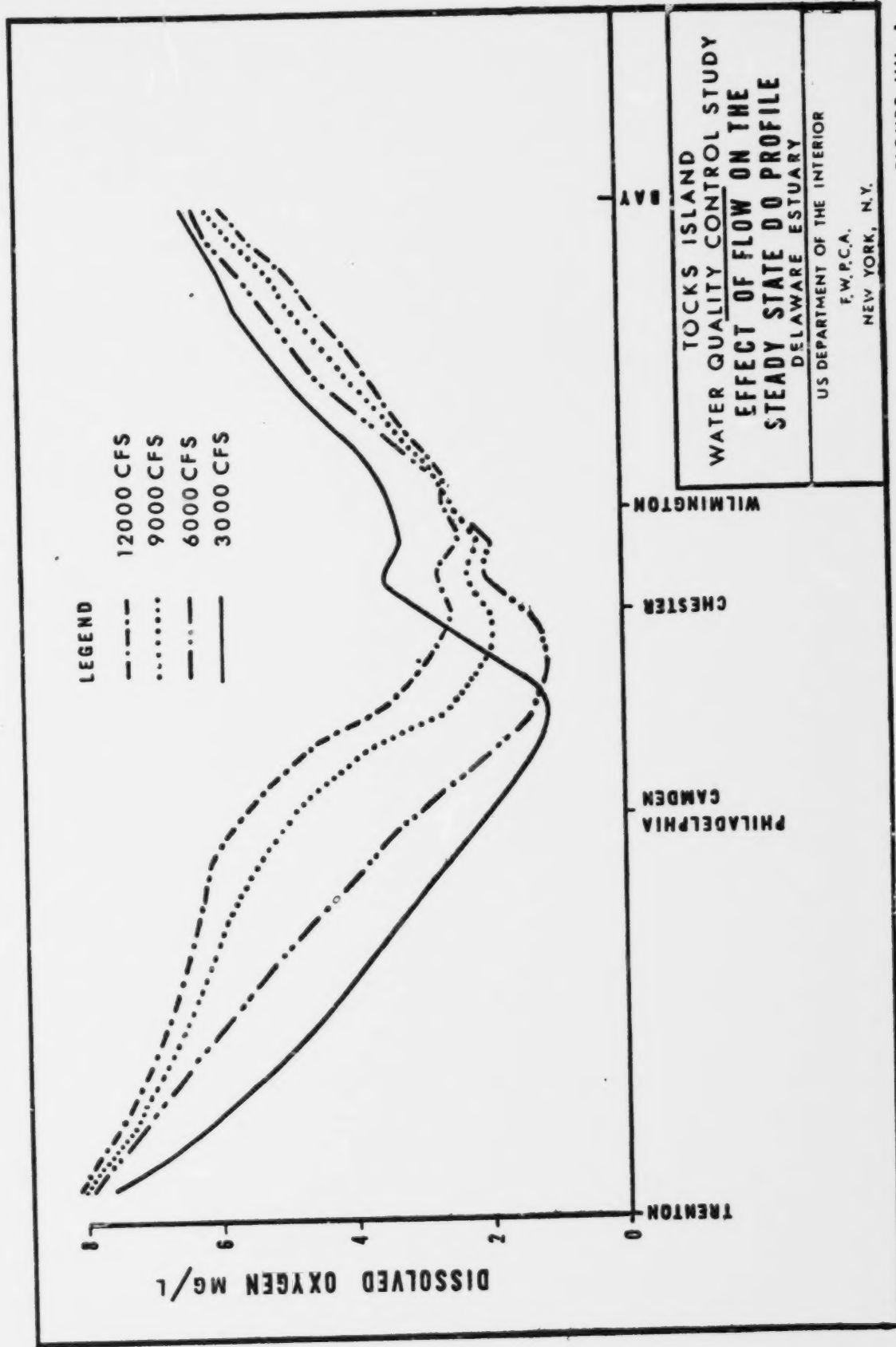


FIGURE VII-1

The increase in the DO in the upper estuary is a result of dilution and decreased transport of a greater portion of the waste downstream. DO decreases in the lower estuary are due primarily to the increased amount of oxygen demanding waste and the transport of lower DO water from upstream.

From these analyses it has been found that an increased flow will increase the DO in certain areas of the estuary, but decrease it elsewhere. Indeed, within the realm of foreseeable flow augmentation schemes (up to a maximum of 6000-7000 cfs), the results indicate that the changes in the DO will be relatively small.

Transient Flow Augmentation

Transient flow as used herein is defined as a temporary fresh water inflow to the Delaware Estuary for a short term interval. Two transient flows were used in these studies: pulse and ramp.

A pulse flow input at Trenton consisted of increasing an existing peak just prior to the start of summer (day 152) low flow to about 24,000 cfs in 15 days and then decreasing to 2,400 in 35 days. Figure VII-2 is a plot of the maximum DO change versus location on the estuary.

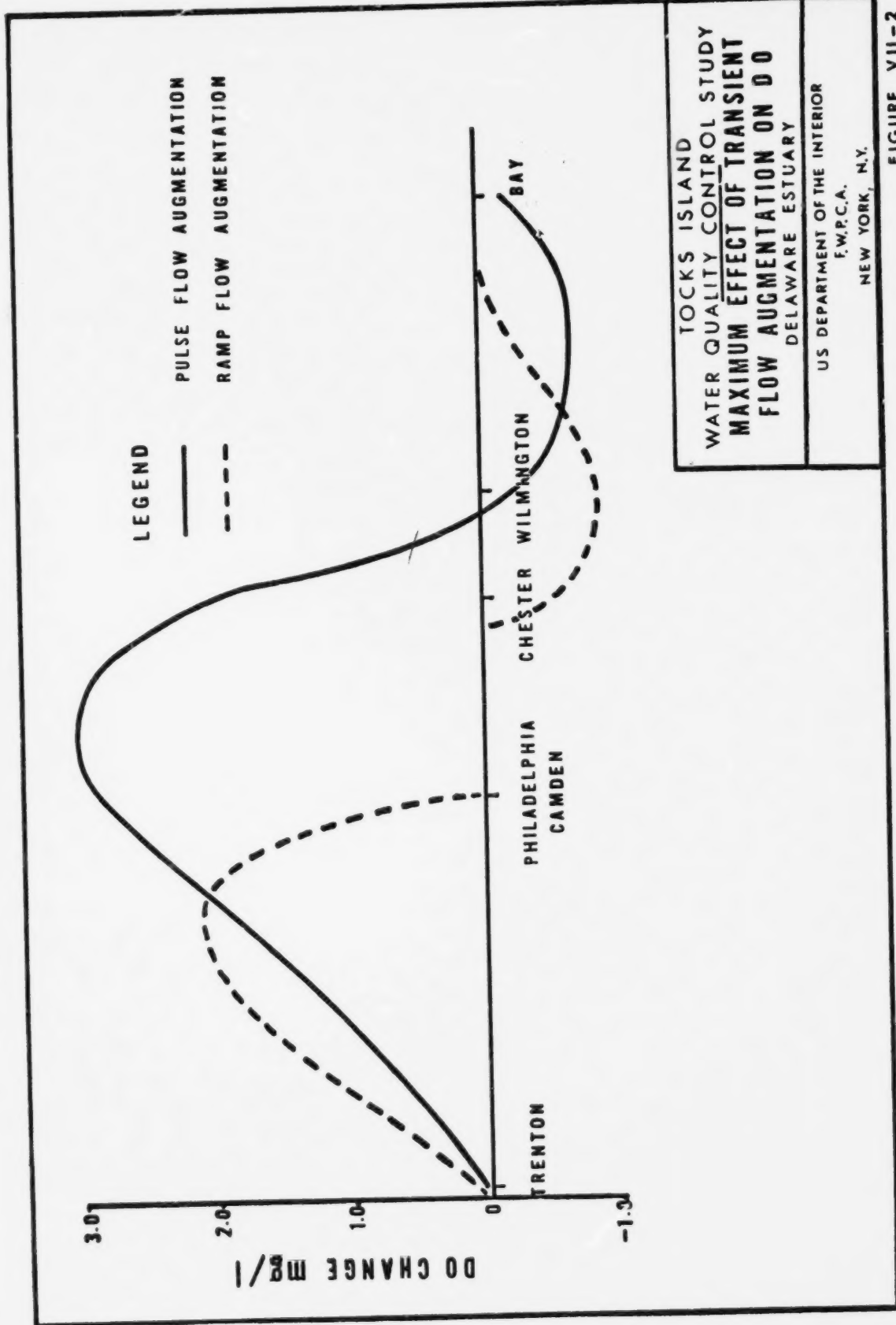
The pulse flow augmentation resulted in a maximum of 3.0 mg/l DO more than with a steady 3000 cfs between Trenton and Philadelphia. From Philadelphia to Wilmington the DO decreases rapidly. Downstream from Wilmington the pulse flow resulted in a decrease in DO of as much as 0.7 mg/l.

The pulse flow augmentation was not very effective and was not sufficient to completely transport the waste to the bay. At any one location this type of flow augmentation resulted in a delay in the occurrence of low DO for one to two weeks, and it did not affect the recovery time. Generally, for the upper estuary an increase in DO was realized for the duration of the augmentation; however, for the downstream sections the DO was decreased for the same period. The decrease is due to the transportation of low DO and high BOD water from the upper estuary. The pulse flow augmentation does not yield DO results which are commensurate with the amount of storage needed. The estuary reverts quickly to DO levels characteristic of its low flow state and the only significant effect is the short delay in the start of low DO conditions.

Figure VII-2 shows the change in DO for a ramp flow augmentation scheme. This flow augmentation scheme starts with a flow of 10,000 cfs and decreases at a uniform rate to 3,000 cfs at day 335.

With the ramp down flow augmentation the improvement in DO in the upper end of the estuary is quite marked. The maximum increase in DO was about 2 mg/l. The DO sag is delayed four to six weeks

VII-11-B



TOCKS ISLAND
 WATER QUALITY CONTROL STUDY
 MAXIMUM EFFECT OF TRANSIENT
 FLOW AUGMENTATION ON DO
 DELAWARE ESTUARY
 US DEPARTMENT OF THE INTERIOR
 F.W.P.C.A.
 NEW YORK, N.Y.

FIGURE VII-2

and the recovery takes place two to three weeks earlier than with usual natural flows. Between Philadelphia and Chester the DO was very low and the ramp flow augmentation did not result in an increase or a decrease in DO for this reach. In the lower estuary the DO was about 0.9 mg/l lower than with a steady 3000 cfs flow, as a result of the transporting of low DO and high BOD water.

The pulse augmentation achieves higher DO but only for a short period, whereas, the ramp augmentation has a lower DO increase but has a longer duration.

Effect of Flow Regulation on Chloride Profile - Delaware Estuary

In order to determine the effects of fresh water inflow on the chloride profile in the estuary, a relatively large analog computer was programmed with the mathematical model of chloride intrusion. The model describes the average chloride concentration over a tidal cycle and within a given reach of the estuary. The period of time used was chosen as one year and to allow reasonable computer time, one second of computer time equalled 10 days of real time. Thus a year's simulation was made in 36.5 seconds of computer time. A total of 100 computer runs were made, using a variety of possible flow regulation schemes. These runs were based on three hydrographs: March 1, 1931 to Feb. 28, 1932, January 1 to December 31, 1963, and January 1 to December 31, 1964.

Verification runs were made using observed daily flows of the Delaware River at Trenton and Schuylkill River at Philadelphia and the chloride concentration of the Bay. With these inputs verifications of the observed time varying chloride profile were made at Wilmington, Chester, and the confluence of Schuylkill and Delaware Rivers. From these verifications, the tidal diffusion coefficients were established and a series of chloride simulation studies were made. All outputs from the computer were recorded on xy plotters. Two general types of flow control schemes were investigated: steady state and transient.

Steady State Flow Augmentation

For the steady state flow augmentation, five flow levels were investigated: 3000, 4000, 5000, 6000 and 8000 cfs. These flows were assumed to be the combined flow of the Delaware River at Trenton and Schuylkill River at Philadelphia. During the simulation of the chlorides the combined flow was maintained at one of the preselected minimum flows. However, if the unregulated

flow was above the minimum then the computer used the higher flow. Thus, these steady state flow augmentation studies provided estimates of the chloride concentrations that would be realized with specified low flow regulation plans.

Figure VII-3 is a plot of the maximum 15 consecutive day mean chloride concentration versus location on the estuary for the 1964 unregulated flow and for selected regulated flow levels.

The chloride profiles were constructed from plots of chlorides versus time for eight stations on the Delaware Estuary from Liston Point to Philadelphia. For each of these stations the maximum 15 consecutive day mean chloride concentration was estimated to construct the profiles in Figure VII-3.

The chloride profiles for the regulated and unregulated flows form a family of curves. These profiles show that as the flow increases the slope of the profile is decreased appreciably up to Chester, Pa. However, below Chester, the chlorides increase rapidly even at fairly high flows.

Figure VII-4 is a plot of the maximum 15 consecutive day mean chloride concentration versus regulated flow. Three locations were selected for this plot, Wilmington, Chester, and the confluence of the Schuylkill and Delaware Rivers. At each location figure VII-4 shows that the chlorides decrease rapidly with increase in flow. At the mouth of the Schuylkill, the upper station of the three, the curve shows that beyond 5000 cfs flow the chloride concentration change is small and the curve becomes asymptotic to the abscissa. In contrast, at Wilmington the chloride concentration change per thousand cfs is very significant beyond the 7000 cfs flow.

Transient Flow Augmentation

The pulse simulation studies assumed flows of 25,000 cfs and 15,000 cfs both for periods of eight and twenty days. Each pulse simulation was used once per year and the pulse flow was applied during three different periods. The pulse flow studies showed that the starting time for augmentation is significant. For example, a pulse flow of 15,000 cfs for a period of twenty days starting at the beginning of summer is not as effective as one starting at the end of summer. The general effect of the pulse augmentation is a rapid reduction of chlorides, i.e., the chloride front is pushed toward the Bay.

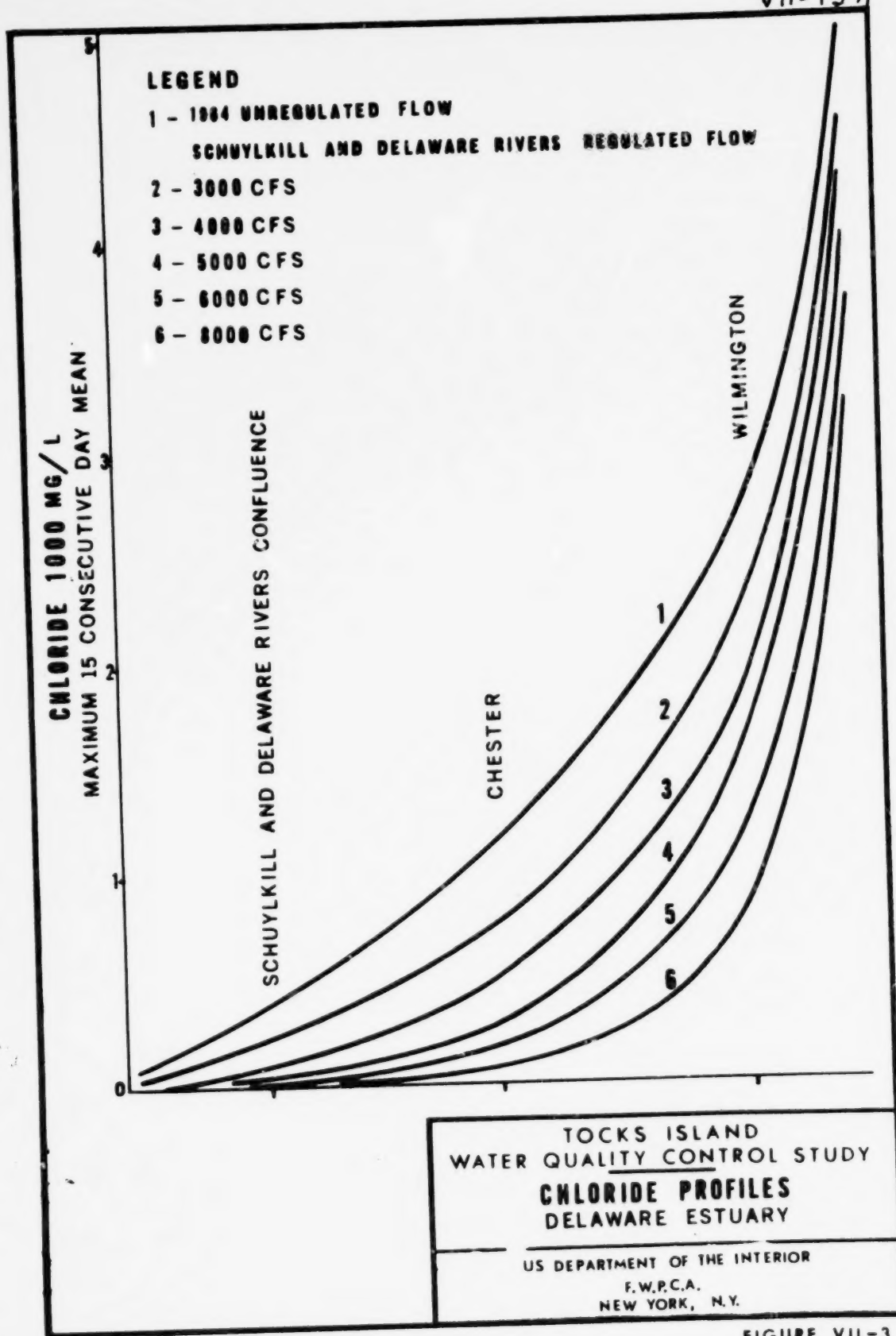


FIGURE VII-3

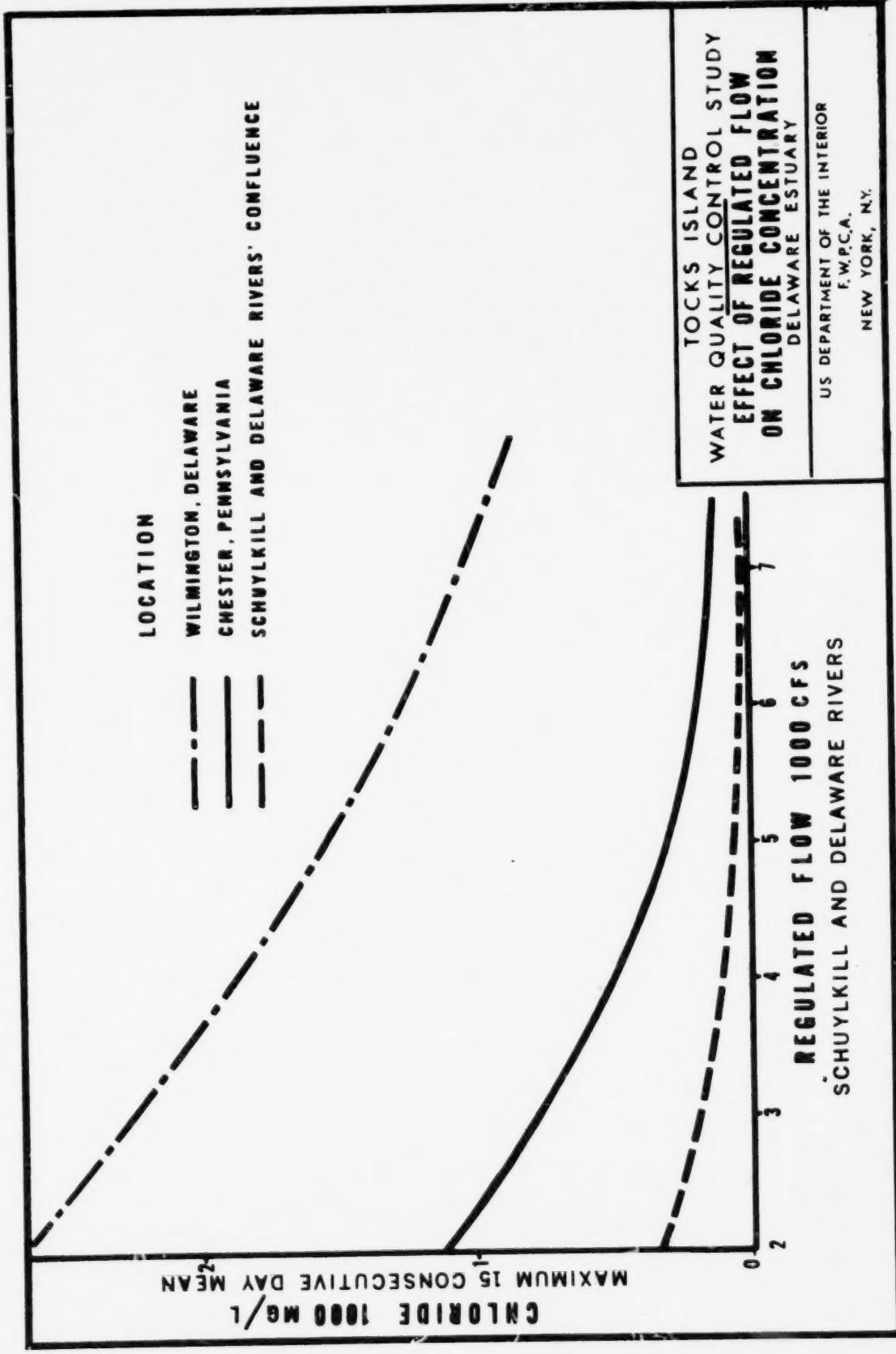
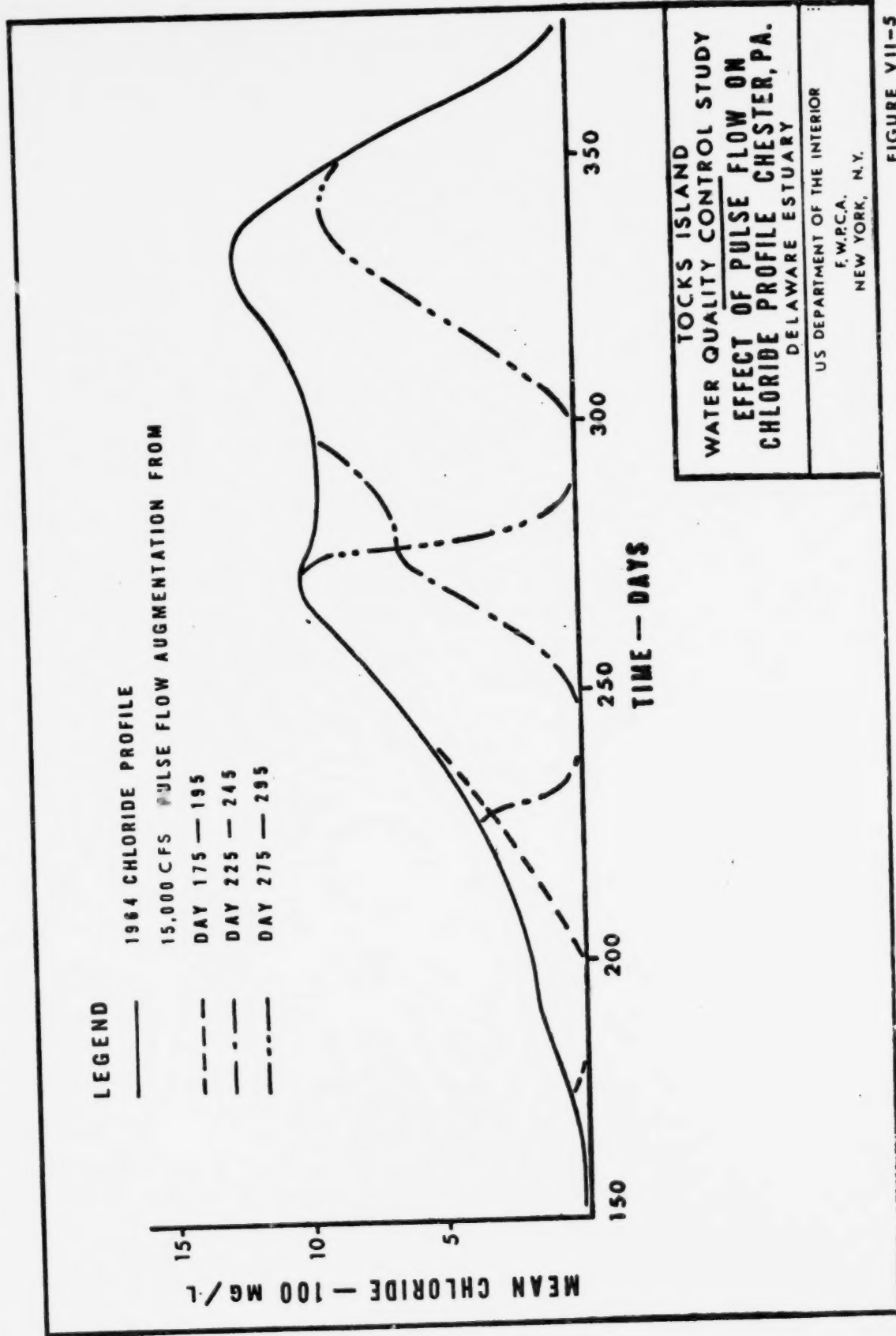


FIGURE VII-4



The effect of 15,000 cfs pulse flow augmentation on chloride profile at Chester is shown on Figure VII-5. The 15,000 cfs flow was maintained for twenty days for three periods: from day 175 to 195, day 225 to 245 and day 275 to 295. The results from this study show that the 15,000 cfs reduced the chlorides at Chester to background chloride concentration during each period of flow augmentation. In each case, once the augmentation was stopped the estuary reverted to its original chloride condition in about 45 days. The rate of chloride increase after augmentation, in all cases, is slower than the rate of decrease at the start of augmentation. The net effect of pulse flow augmentation is that the chlorides are pushed back towards the bay for a period equal to the period of flow augmentation. Once the high flow is stopped, tidal diffusion pushes the chlorides upstream and the rate of return is a function of the total flow into the estuary.

Similar results from pulse flow augmentation were observed at Wilmington. However, downstream from Wilmington, neither the 15,000 nor 25,000 cfs were sufficient to reduce the chloride concentration to background concentration.

Two ramp up flow chloride simulation studies were investigated. One started with a flow of 3,000 cfs and increased to 9,000 cfs in 135 days (June-October). Another started at 2,000 cfs and increased to 9,000 cfs in 85 days (August-October).

Of the two ramp up flow augmentation schemes investigated, the scheme providing for a gradual flow increase from 3000 cfs to 9000 cfs resulted in a greater reduction of chlorides primarily because it used a greater volume of water. In both cases when the augmentation was stopped the chloride front started moving upstream rapidly, with the greatest rate of increase at the lower end of the estuary. The maximum chloride reached after augmentation varied from 77% of that observed in 1964 at Wilmington to 27% at the confluence of the Schuylkill and Delaware Rivers. For both flow schemes the maximum chloride concentration was the same even though the 2,000-9,000 cfs was started 50 days later. The time difference in the start of the augmentation allowed the chloride barrier to move sufficiently upstream that significant chlorides were realized before the starting date. Since both augmentation schemes ended at the same flow and time the end points of the chloride concentrations were about the same. As soon as the augmentation was stopped the chlorides started moving upstream very rapidly until they were checked by the normal increase in flow in the fall.

Need for Storage for Water Quality Maintenance

Delaware River - Section 2

From the proposed Tocks Island Reservoir to Trenton, under the anticipated minimum regulated flow of 1750 cfs at Montague, the minimum DO will be greater than 5.0 mg/l (see Effect of Flow Regulation on DO profile - Delaware River - Section 2). Therefore, available flows and provision of adequate treatment of present and anticipated waste loads is sufficient to maintain water quality so that storage for flow augmentation is not required for water quality control to year 2010.

Delaware Estuary - Section 3

As previously noted (Effect of Flow Regulation on DO Profile - Delaware Estuary) the DO increases and decreases to be expected from possible ranges of sustained fresh water inflow are relatively small. For a range of desirable DO goals, increases in fresh water inflow (within reasonable flow augmentation schemes) will not have a substantial effect on the minimum DO levels in the estuary. Therefore, according to the DO simulation studies made, it appears that provision of storage for assimilation of organic waste is not required to improve the dissolved oxygen concentration in the estuary. Indeed, as is pointed out in Chapter VIII - Benefits, increases in fresh water inflow may in fact be detrimental for DO control.

Increased fresh water inflow can effectively control maximum chloride concentrations in the upper estuary. Maximum chloride concentrations affect the use of the estuary for municipal and industrial water supply and may in fact eliminate it as a source.

The Philadelphia Delaware Estuary water supply intake is approximately 17 miles above the mouth of the Schuylkill River. In 1964 the maximum chloride concentration observed at this water intake by the U.S.G.S. was 65 mg/l. Thus, for the 1964 low flow condition, the estuary was a good water supply source, so far as chlorides were concerned. Furthermore, with the future regulated flow of 1750 cfs at Montague and the completion and operation of Beltzville, Blue Marsh, and Tocks Island Reservoirs by the Corps of Engineers, a minimum flow of 3124 cfs of the Delaware at Trenton and 415 cfs from Schuylkill River at Philadelphia will be realized. This minimum regulated flow will provide the Philadelphia water supply additional protection from chloride intrusion.

Camden presently relies on 35 wells for its source of potable water. This city has not yet experienced any chloride intrusion from the estuary into its aquifer. Should the city decide to use the estuary directly as a source of water supply, it would be assured low chloride water.

In 1951 Chester abandoned the Delaware Estuary as its source of water supply primarily because of the high chloride concentrations during low runoff years. Presently, this city is using Octoraro Creek (Susquehanna River Basin) for a water supply source.

The 2010 water supply demand for the Chester Water Authority service area is estimated to be 74 mgd. The Octoraro Creek Water Supply source has a safe yield of 30 mgd and it is estimated that this will be sufficient to meet the demand until 1970. By 2010 the Chester area will need an additional 44 mgd.

Industries in the area from the Schuylkill River to the Pennsylvania-Delaware state line on both sides of the Delaware Estuary are presently using 65 mgd of Delaware Estuary water for process and boiler feed and 1010 mgd for cooling. By year 2010 the total industrial process and boiler feed water use will be about 161 mgd or an increase of 96 mgd and 3440 mgd for cooling water.

The Delaware Estuary is undoubtedly the most readily available source of supply for the additional 2130 mgd cooling water, 96 mgd for industrial process and boiler feed water, and 44 mgd for the Chester Water Authority by 2010. However, because of the high chloride concentration, the river in the area during periods of low flow is not a desirable water supply source, for either potable or industrial use. Hence, the Chester Water Authority additional water supply demand and the industrial process demand could not be met from the Delaware Estuary unless 1) there is some guarantee that flow augmentation will result in a low chloride water, 2) an economically desalination process is developed, 3) or water is piped to the area from upstream. There does not appear to be any economically feasible method of supplying the present and future cooling water demand from other sources than the estuary.

To meet the future water supply demand for their service area the Chester Water Authority is looking at other sources. The Octoraro Creek water supply may be developed to a safe yield of 50 mgd from its present 30 mgd. Hence, the authority requested approval to expand this source. However, there is considerable opposition to the expansion of the project from the local people and the Chester Water Authority has not yet been issued a permit.

The present source of water being considered to meet their immediate demand is the Conowingo Pool on the Susquehanna River. To use this source will require a pumping station and a ten mile transmission line to the Octoraro Creek impoundment.

As stated above, industries are presently using the Delaware Estuary as a water supply source and during low flows are experiencing considerable difficulty and additional expenses for maintenance due to corrosion and scale. In fact, some industries which cannot tolerate water with a chloride concentration greater than 150 mg/l have arranged to purchase water from the Chester Water Authority, thus putting a burden on the Authority's system. However, there is no alternative source available to these industries for cooling water. In view of the foregoing, the use of storage in the reservoirs proposed in the Delaware River Basin Report (1) for the upper Delaware River and Schuylkill River should be considered for maintaining the chloride goal of 250 mg/l at Chester (mile 80).

Table VII-1 shows the effect of anticipated storage projects on minimum flows during dry periods and the effect of these flows on the location of the 250 mg/l chloride concentration in the Delaware Estuary. A minimum flow of 2850 cfs is based on the required releases by New York City from its reservoirs to maintain 1750 cfs at Montague, intervening uncontrolled flow between Montague and Trenton expected to add 750 cfs, and a minimum flow of 350 cfs in the Schuylkill River at Philadelphia. Flow increments are based on the water supply allocations made by the Corps of Engineers in the Delaware River Basin Report (1) with the exception of Beltzville and Tocks Island. For these two reservoirs the data is based on the most recent planned and anticipated developments.

To assure the chloride water quality goal for the Chester area (mile 80) 24 out of 25 years, it is estimated that the combined minimum flow of the Delaware River at Trenton and Schuylkill River at Philadelphia should be 6200 cfs. Assuming that 4044 cfs would be available by 1990 it is estimated that 642,000 acre feet of annual draft on storage, including 10% for synchronization of releases and other losses, would be required to maintain 6200 cfs.

TABLE VII-1

VII-18

CUMULATIVE FLOWS & CHLORIDE LOCATION

Corps of Engineers Project	Flow Increments CFS	Cumulative Minimum Flows - CFS			Appropriate Location of 250 mg/l Cl(d) Concentration Miles
		Delaware River @ Trenton	Schuylkill River @ Phila.	Total	
None	-	2500(c)	350	2850	95 (Confluence of Schuylkill and Delaware R.)
Beltzville	94(a)	2594	-	2944	-
Tocks Island	530(b)	3124	-	3474	-
Blue Marsh	65	-	415	3539	89 (Mantua Creek)
Trexler	55	3179	-	3594	-
Prompton	57	3236	-	3651	-
Aquashicola	63	3299	-	3714	-
Maiden Creek	134	-	549	3848	-
Bear Creek	196	3495	-	4044	87 (Clonmell Creek)

(a) Assumes 56 cfs for water supply and 38 cfs for water quality control.

(b) Of a total flow increment of 980 cfs, 450 cfs is planned for out of the basin diversion and hence is not included.

(c) Minimum average daily flow during record drought (to 1963) and is based upon releases from New York City reservoirs maintaining 1750 cfs at Montague.

(d) Maximum 15 consecutive day mean chloride concentration. For approximate maximum and minimum concentration location subtract or add about 2.5 miles respectively.

VIII. BENEFITS OF WATER QUALITY CONTROL

Dissolved Oxygen

Delaware River - Section 2

As was indicated in Chapter VII, satisfactory DO levels will be maintained in this section of the river without any additional flow regulation. However, as could be seen below, flow regulation for chloride control will result in incidental water quality benefits from Tocks Island to Trenton. These benefits may be such as to forestall the need for advanced waste treatment facilities. The monetary value of these benefits has not been estimated.

Delaware Estuary - Section 3

Extensive investigations are being made by the DECS to determine the most economical means of water quality control in the Delaware Estuary by waste treatment and flow regulation. Given a series of DO goals and the waste load inputs to the estuary, the costs of attaining the goals have been computed for three different approaches: (a) uniform treatment for all waste discharges, (b) uniform treatment for waste discharges within specified zones (two zone configurations have been worked out), and (c) treatment for each waste discharge to attain minimum regional cost. Treatment costs were computed as a function of fresh water inflows at Trenton of 3000 and 6000 cfs and minimum average daily DO goals of 2.0, 2.5, 3.5 and 4.0 mg/l.

From these studies, waste treatment cost has been found to vary with the DO goal and the flow. For low DO goals the cost decreases with an increase in flow, for intermediate DO goals, the cost increases with an increase in flow, and for high DO goals there is no apparent change with flow. On setting a DO goal for the estuary, the positive or negative benefits from flow regulation may be estimated.

The most economically feasible method for dissolved oxygen control in the Delaware Estuary is being sought by the Delaware Estuary Comprehensive Study. These studies show that the waste treatment cost is a function of the fresh water inflow, DO goals and waste treatment program employed. In as much as the latter two variables have not been defined, estimates of waste treatment cost differences due to increases in flow cannot be made at this time and flow regulation is not being proposed for control of any pollutants other than chlorides.

Chlorides

Delaware Estuary - Section 3

Providing flow regulation in the Delaware Estuary will assure Chester, other communities in this area, and the industrial water users, lower chloride concentrations and a water supply source sufficient to meet the expected additional 2010 domestic water supply demand of 24 mgd and 2130 mgd cooling, process, and boiler feed water.

Present and potential industrial water users will also benefit from lower chlorides in the estuary. Many industries consider uniform water quality over time to be beneficial because of reduced operation and maintenance cost. However, for some processes requiring a chloride concentration of less than 150 mg/l, industry may still have to rely on alternate sources.

The industries using the estuary have experienced and will experience additional costs for operation and maintenance of equipment during low flow-high chloride concentration periods. The additional costs are a result of corrosion of equipment and pipes, loss of production time for maintenance and replacement of equipment, and increased frequency of boiler blowdown. For some industries where process water becomes part of the product, high chloride concentrations are not tolerable.

By maintaining a control level of a maximum 15 consecutive day mean chloride concentration at or below 250 mg/l at Chester (mile 80), a large water supply source will be made available for municipal and industrial water supply users in the estuary between Philadelphia and Chester. This chloride goal will assure all industries above mile 80 a dependable low chloride water. Industries below mile 80 will realize lower chlorides. Also there will be a reduction in the maximum concentrations.

Flow regulation or a tidal barrier may be employed in the Delaware Estuary to assure a low chloride water for all uses. A preliminary study on the feasibility of constructing and operating a salt water barrier on the Delaware Estuary was made by the Corps of Engineers and their finding is reported in the Delaware River Basin Report (1). From their study they conclude that "...it would be feasible from an engineering standpoint to construct, operate, and maintain a barrier across Delaware River in the vicinity of New Castle, Delaware, and that such a barrier would effectively halt

the intrusion of salt water, creating a large fresh water lake which would provide a suitable source of water supply for northern Delaware. It has been further shown that the barrier would have complex and far-reaching physical and economic effects on water-supply, navigation, flood control, fish and wildlife, recreation, and industry. Consideration of all these factors does not disclose any clear-cut justification for making additional detailed studies of the proposed project at this time..."

Flow augmentation may be employed in the Delaware River Basin to control the chloride intrusion in the Delaware Estuary. Storage for flow augmentation may be obtained from additions to proposed Corps of Engineers reservoirs, enlarging existing reservoirs, developing new single and/or multiple purpose reservoirs or any combination of these three alternates. At this time flow augmentation appears to be the only economically feasible method for controlling chloride intrusion into the estuary.

To estimate the annual draft on storage to control the chloride intrusion, two stages of reservoir development for providing the necessary storage releases for maintaining the chloride goal have been considered. The first is based on the completion and operation of Tocks Island, Beltzville and Blue Marsh Reservoirs in addition to the maintenance of 1750 cfs at Montague, New Jersey, by the city of New York, as required by the 1954 Supreme Court Decree. The second stage is based on the complete development of all the eight proposed Corps of Engineers multipurpose reservoirs (see Table VII-1) as presented in the Delaware River Basin Report (1).

For each of the two stages of development, the additional storage releases needed to achieve the chloride goal was computed. Table VIII-1 summarizes the anticipated flows expected for the two stages of development and the storage computed for two drought probabilities: 0.04 and 0.02. These are the one in twenty-five year and one in fifty year drought occurrences, respectively.

Table VIII-1 shows the flow-draft on storage relationship for the 0.04 and 0.02 probabilities, and shows that as the severity of the drought protected against increases the annual draft on storage increases. Considering the present (1964-1965) drought being experienced, the increase in cost with the increase in protection level and the loss that could occur in case of failure to maintain quality, the one in twenty-five year drought is being used as a basis for design. To maintain the chloride goal throughout the Chester area it is estimated that the minimum combined flow from the Schuylkill River at Philadelphia and Delaware River at Trenton should be 6200 cfs.

TABLE VIII-1

VIII-4

FLOW - DRAFT ON STORAGE

Expected Minimum Flow - CFS			Required Flow for 250 mg/l(a) @ Chester CFS	Necessary Draft on Storage Acre Feet	
Delaware R. @ Trenton	Schuylkill R. @ Phila.	D.R. and S.R.		PR=0.04	PR=0.02
3124	415	3539(b)	6200(d)	756,000	868,000
3124	415	3539(b)	6800(e)	956,000	1,153,000
3495	549	4044(c)	6200(d)	642,000	733,000
3495	549	4044(c)	6800(e)	842,000	1,018,000

(a) Maximum 15 consecutive day mean over a tidal cycle.

(b) Expected with Beltzville, Tocks Island, and Blue Marsh Projects.

(c) Expected with Beltzville, Tocks Island, Blue Marsh, Trexler, Prompton, Aquashicola, Maiden Creek and Bear Creek Projects.

(d) With present channel configuration.

(e) With proposed deepened and widened channel.

Estimates have also been made of the flow necessary to keep the chloride concentration at Chester at or below 250 mg/l for an optimum navigation channel as proposed by the Corps of Engineers. This channel would be wider, have enlarged anchorages, and be fifty feet deep up to and including Philadelphia. For the proposed channel configuration it is estimated that a combined flow from the Delaware River at Trenton and Schuylkill River at Philadelphia of 6800 cfs is needed to keep the chloride concentration at or below 250 mg/l at Chester (mile 80).

The eight proposed multipurpose Corps projects are estimated to assure 4044 cfs during a 25 year drought. To make up the flow needed for the one in twenty-five year drought, based on flows of record through climatic year 1965, it is estimated that an additional 642,000 acre feet of draft on storage is necessary (including 10% of additional storage for all losses). Based on an economic life of 50 years, an interest rate of 3.125 per cent for a federal project, and an operation and maintenance cost of \$260,000 per year, this storage may be obtained from a single purpose reservoir at an annual cost of \$4,900,000. The annual cost has not been discounted since the 6200 cfs is presently needed to maintain quality for industrial and municipal use purposes and such regulation as Tocks Island could provide will improve quality in the interim period before all other authorized projects are completed.

Municipal Chloride Benefits

To estimate the dollar benefit that may be obtained by assuring relatively low chloride water for the Chester Water Authority, four alternatives for obtaining a comparable water supply source have been investigated: (1) Susquehanna Pipeline, (2) desalination, (3) storage pipeline, and (4) Delaware Pipeline. The cost of the cheapest alternative which the community might adopt to meet their future water supply needs is an estimate for part of the benefits to be derived from maintaining water quality through storage of water in multipurpose reservoirs proposed to be constructed by the Corps of Engineers. These alternatives are evaluated below:

Susquehanna Pipeline. To meet their additional water supply demand to 1990, the Chester Water Authority has obtained a permit to divert as much as 60 mgd from Susquehanna Basin. Plans are now being made by the Authority to obtain the additional water supply to meet their demand by diverting water from the Conowingo Pool on the Susquehanna River to the Octoraro Reservoir, a distance of 10 miles. Beyond 1990 the authority will have to increase its diversion from the Conowingo Pool or make other water supply arrangements if flow regulation or any other scheme is not employed to reduce the chloride concentration of the Delaware Estuary to a potable level.

The cost to divert 24 mgd of water from the Conowingo Pool to the Octoraro Reservoir from 1990 to 2010 is one alternate to estimate the benefits for having chloride concentrations less than 250 mg/l in the Delaware Estuary. The 1990 value using an interest rate of 3.125 percent, for the construction, operation and maintenance of a 36 inch - 10 mile pipe is estimated to be \$4,662,000 and purchase of water from the Conowingo Pool. Discounted to 1960 this cost is \$1,851,000. Amortized for a fifty year period at 3.125 percent the equivalent annual cost is \$73,500.

Desalination. Desalination of Delaware Estuary water for use as a domestic and industrial water supply has been considered as a possible means of meeting the future additional water supply demand. Based on anticipated future population and industrial growth it was estimated that an additional 24 mgd of water low in chlorides will be needed by the Chester Water Authority for the period 1990-2010. This assumes that Chester will carry out present plans to develop a safe yield of 50 mgd by 1990. Estimates of costs to obtain the additional 24 mgd have been prepared for the construction and operation of a desalination plant utilizing the electrodialysis process.

The electrodialysis process is the most economical process now available for removal of chlorides. For best operating efficiency, cooling water from power plants or from industries can be used, resulting in lower operating costs. The electrodialysis process requires that water be pretreated by conventional treatment processes. However, the cost for conventional treatment has not been included since all of the alternatives require conventional water treatment.

The combined annual cost to desalinate water with approximately 1400 mg/l of chlorides to 250 mg/l is estimated to be \$364,000 for a 50 year period at an interest rate of 3.125 percent. The fixed cost to install the plant is \$7,440,000 not including site cost, site preparation, water storage, and electrical substation. Discounted to 1960 the fixed cost is \$4,000,000. Operation and maintenance (O&M) present value (1990) for a seven months year for 20 years are estimated to be \$13,300,000. Discounted to 1960 the O&M costs is \$5,200,000.

The major cost for desalination is for operation and maintenance. With changes in technology desalination by electrodialysis or by some other method may become an economically feasible method of obtaining potable water. If there is delay in authorization of Tocks Island Project, it is recommended that developments in the field of desalination be reviewed before including storage for chloride control.

Storage and Pipeline. Another alternative to supply the additional water supply need of 185 mgd is to store water in the Schuylkill River Basin and pump it from the Schuylkill River to the Chester area.

A water transmission line from Chester to the Schuylkill River at the Fairmount Pool would be about 14.5 miles, 4.5 miles longer than the Chester-Susquehanna pipeline. The cost to lay down 14.5 miles of pipe would have a higher cost per linear foot because the area is highly developed. In addition, storage would have to be provided for the 24 mgd, since the 1 in 25 year - 15 consecutive day adjusted low flow is 310 cfs, 50 cfs less than what is allocated to the city of Philadelphia.

Delaware Pipeline. The additional 24 mgd water supply demand for the Chester Water Authority may be obtained further up the Delaware Estuary where the chloride goal of 250 mg/l is attainable without additional flow augmentation. Table VII-1 shows that this may be available at mile 87. However, this is a mean value over a tidal cycle and would require intermittent pumping and storage of fresh water. Three major municipal water pollution control plants discharging waste at mile 93, 96, and 98, presently provide only primary waste treatment. It is expected that these plants will be providing secondary treatment in the near future, however, another major plant at mile 105 presently provides secondary treatment. It is considered desirable to have the water intake above the treated sewage discharges and above the influence of the last water pollution control plant. The latter requirement would avoid treated sewage that the tide "pushes" upstream. Locating the water intake at mile 110 would protect the water supply from accidental bypasses at the water pollution control plant, from inefficiency in operation, and from combined storm water overflow. However, the maximum 15 consecutive day mean chloride concentration of 250 mg/l will be realized at mile 87. A water supply intake at this source may assure the low chloride water but would not be an ideal location for aesthetic purpose. Hence the additional cost to put the water intake upstream from the sewage outfalls should be charged to the water pollution control program and should not be used in the calculation of benefits resulting from flow regulation. The Delaware River pipeline will have a higher cost per linear foot than the Susquehanna pipeline because the area is highly developed along the Delaware Estuary. Consequently, a detailed cost estimate was not made.

The Chester Water Authority will probably continue to use its present water supply source and any other source that they may develop until such a time as complete replacement of their filtration plant and transmission line is necessary. Then they will re-evaluate the estuary as a potable source. Also they may use the estuary during low chloride periods and switch to their other sources during chloride intrusion or perhaps blend waters from the two sources if necessary.

Industrial Chloride Benefits

The estimation of industrial chloride benefits is a complex process highly influenced by local characteristics. It was apparent that benefits would accrue, but the process by which this occurs is extremely variable. There are plants that would have virtually no benefit, due to the use of highly resistant materials in equipment that contacts river water. Others follow an operating policy that avoids use of the estuary during critical periods of the year; furthermore, they are not inclined to change such a policy unless changes in the river are on a long-term and consistent basis. A third class may attempt some treatment of intake water, and simply sustain some measure of damage (e.g. corrosion) in their system, which is reflected in periodic maintenance.

In an attempt to account for these factors, data were requested from a number of firms along the estuary. The data reflected all three classes, as well as some plants that showed characteristics composed of a mix of the three. As might be expected in any operation as complex as a modern industrial plant, many respondents experienced considerable difficulty in translating specified chloride decrements in their intake water into dollar benefits. In most cases, the chain of cause and effect relationships between river water and monetary savings had not been previously quantified. It should be realized that such quantification requires the measurement of water characteristics, corrosion rates, treatment and maintenance costs over a period of time. The implementation of such programs in estuary industries is only in the initial stage; for this reason the benefit estimates were made using the best available information, but supplemented with the professional judgment of technical personnel intimately involved with the operation of the plants.

In spite of these difficulties, a number of respondents succeeded in estimating dollar-benefits as a function of chloride depression. These data were then generalized statistically for application to other industries along the estuary. Benefits were considered to accrue

in areas exhibiting significant chloride depression, approximately from mile 65 to mile 104, providing that such areas were not so far down the river that plants characteristically employed resistant materials in their equipment. The dollar benefits were considered to be a function of (1) the quantity of water used, (2) location on the estuary, (3) the depression of chlorides below present levels. A response-surface technique was applied to obtain the statistically best estimate of annual benefit given the three input variables for any industry. The statistical estimates were also dependent on the type of industry, because separate data were generally available for petroleum, chemical, and paper manufacturing industries. For plants not in any one of these three categories, benefits were derived by means of the response surface based on all three categories of data. The total benefit in annual terms was then the aggregation of all individual industry values, of which some were based on original interview data and others on the statistical estimates derived from the response surface. In all cases the benefits represent a dollar value which would accrue as a result of long-term conditions. The chloride levels are assumed to be relatively stable at the new lowered values over a number of years.

Purchased water. An inventory of water use by the Delaware Estuary Comprehensive Study shows that 11 mgd of industrial process and boiler feed water are purchased from the local water authorities between the mouth of the Schuylkill River and the Pennsylvania-Delaware state line. If an economical desalination process is developed or a water resources program reduces the chloride intrusion to make it a desirable source this 11 mgd now purchased by industries could be released for domestic use. It is estimated that by 2010, industries may be buying about 30 mgd. Industries on the New Jersey side of the estuary have developed private wells. Some of these industries used the Delaware Estuary as a source of supply in the past. However, because of the high chlorides concentration they have abandoned the estuary as a source of supply.

The minimum rate being paid by these industries is 15¢/1000 gallons. Data from the Chester Municipal Authority show that the operating cost of the old water treatment plant that utilized the Delaware Estuary was \$40.38/million gallons or 4.038¢/1000 gallons. If flow regulation is provided to maintain the chloride concentration at or below 250 mg/l, the Delaware Estuary will become a more desirable source of water supply. It is estimated that Delaware Estuary water could be treated by the industries at a cost of 5¢/1000 gallons. This could result in a savings of about 10¢/1000 gallons. The immediate direct identifiable benefit to the industries

presently using municipal sources from the reduction of chlorides would be therefore \$400,000 per year. For a 50 year period the present value (1960) is \$16,400,000. On an annual basis the cost is \$650,000. This is one directly measurable cost to industry of high chlorides.

The chloride benefit study shows that the industries using Delaware Estuary water from central Philadelphia to southern Wilmington will benefit by a flow regulation program to control chloride intrusion. These industries account for 1960 surface water use of 1076 mgd. This total flow does not include water use by industries and public utilities that would not realize a benefit from chloride reduction.

Analysis of the chloride benefits shows that they vary directly with fresh water inflow to the estuary, use, and location on the estuary.

The chlorides benefits are presented in Table VIII-2. This table shows the quantifiable benefits for 1960, the approximate net flow and location and total water use.

TABLE VIII-2
INDUSTRIAL CHLORIDE BENEFITS

Fresh Water Inflow	Approximate Location of 250 mg/l Cl(a) Concentration	Cumulative Chloride Benefits for 1960 Water Use	Equivalent Uniform Annual Chlorides Benefit	Total Industrial Water Use	
				(1965) MGD	(2010) MGD
cfs	miles	\$/year	\$/year		
4044	87	2,260,000	3,960,000	1076	3300
6200	80	3,447,000	6,060,000	1076	3300

(a) Maximum 15 consecutive day mean over a tidal cycle.

The industrial surface water use for the industries using the Delaware Estuary is estimated to be 3300 mgd in 2010. To account for the benefits for the increasing water use, the increasing benefits (gradient series) were converted to an equivalent Uniform Annual Series Benefit using a 50 year period and 3-1/8%.

SUMMARY

Of the four alternatives for estimating the chloride benefits for the Chester Water Authority investigated above, the Susquehanna pipeline is the most economical. If the chlorides in the Delaware Estuary at Chester, Pa. (mile 80) are controlled so as not to exceed a maximum 15 consecutive day mean over a tidal cycle of 250 mg/l, the annual benefits may be about \$73,500 which is equal to the cost of the Susquehanna pipeline (See VIII-5) and purchase of water from the Conowingo pool. An economical and feasible method for chloride control is flow regulation. These benefits then will be realized if the 15 consecutive day minimum low flow is equal to or greater than 6200 cfs.

The total benefits that may be realized are a function of the fresh water inflow into the estuary. These benefits are summarized in Table VIII-3. The incremental benefit attributable to reservoir releases from projects as already planned is \$3,960,000 per year. The benefits directly attributable to incremental quality control storage of providing an additional 2156 over 4044 cfs (or 6200 cfs) is \$2,173,500 per year.

TABLE VIII-3

TOTAL CHLORIDE BENEFITS

Expected Delaware and Schuylkill Rivers Flow	Cumulative Benefits			Incremental Benefits
	Industrial	Municipal	Total	
CFS	\$/year	\$/year	\$/year	\$/year
6200	6,060,000	73,500	6,133,500	2,173,500 *
4044	3,960,000	None	3,960,000	-

*Incremental benefit directly attributable to quality control storage.

While storage for water quality control in Section 2 is not necessary, the increased flows for chloride control will further improve water quality in this area. This will then insure a high degree of protection of present and future water uses.

The benefits realized from reduction of chloride concentrations will extend throughout the Delaware Estuary. Consequently, these benefits are considered widespread and general.

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WATER POLLUTION CONTROL PLANTS

IX-3

DELAWARE RIVER

Section 2

State County Sub-Division	1960 Population Population Served	Degree of Treatment	Receiving Stream
New York			
Orange			
Port Jervis	11,000 (s) 9,441 (w) 11,000 (s) 9,441 (w)	Secondary	Neversink River
Pennsylvania			
Monroe			
East Stroudsburg	7,674 X	Secondary	Sambo Creek <u>a/</u>
Stroudsburg	6,070 6,000	Secondary	Brodheads Creek
Northampton			
Easton	31,955 42,000	Secondary	Delaware River
Bangor	5,766 5,000	Secondary	Martins Creek
Penn Argyl	3,093 3,000	Secondary	Waltz Creek
New Jersey			
Warren			
Phillipsburg	18,502 18,315	Secondary	Delaware River
Hunterdon			
Frenchtown	1,340 1,000	Secondary	Delaware River
Lambertville	4,269 3,000	Secondary	Delaware River

a/ Tributary to Martins Creek

WATER POLLUTION CONTROL PLANTS

DELAWARE RIVER

Section 3

State County Sub-Division	1960 Population Population Served	Degree of Treatment	Receiving Stream
Pennsylvania			
Philadelphia			
Philadelphia N.E.	2,002,512 669,000	Secondary	Del. Estuary
Philadelphia S.E.	2,002,512 667,500	Primary	Del. Estuary
Philadelphia S.W.	2,002,512 870,000	Primary	Del. Estuary
Central Delaware Co. Sewer Authority	- 70,000	Primary	Del. Estuary
Chester	63,700 100,000	Primary	Del. Estuary
New Jersey			
Mercer			
Trenton	114,000 197,000	Secondary	Del. Estuary
Camden, South	117,159 120,000	Primary	Del. Estuary
Delaware			
New Castle			
Wilmington	95,827 225,000	Primary	Del. Estuary

INDUSTRIAL WASTE DISCHARGES

IX-5

DELAWARE RIVER

Section 2

State County Industry	Waste MGD	Degree of Treatment	Receiving Stream
New Jersey			
Warren			
J.T. Baker Chemical Co.	3.0	High Primary	Delaware River
Inco Container	X	X	Pophandusing Cr.
Pearsall Chemical	0.1	Primary	Delaware River
Riegel Paper Co.	5.0	Primary	Delaware River
Sanco Piece Dye Works	2.0	None	Delaware River
Hunterdon			
Riegel Paper Co.	1.5	Primary	Musconetcong River
Riegel Paper Co.	5.0	Secondary	Musconetcong River
Riegel Paper Co.	10.0	Primary	Delaware River
Tizon Chemical Co.	0.1	Primary	Wickechoke Creek
Mercer			
General Motors Corp.	0.3	X	Cold Run
U.S.N. Aeronautical Test Lab.	X	X	Cold Run
Pennsylvania			
Northampton			
Blue Ridge Textile Co.	0.4	High Primary	Martins Run
Alpha Portland Cement Co.	1.5 a/	X	Martins Creek
P.P. & L	0.1 <u>5/</u>	Primary	Delaware River
Monroe			
Coates Board & Carton Co.	1.0	Secondary	Broadhead Creek
Bucks County			
Whipany Paperboard Co.	2.0	High Primary	Durham Creek
Union Mills Paper Mfg. Co.	2.1	Secondary	Delaware River
Cold Spring Bleachery	0.3	High Primary	Brock Creek
a/ Cooling Water			
5/ 130 MGD cooling water			
X Not Known			

INDUSTRIAL WASTE DISCHARGES

IX-6

DELAWARE ESTUARY

		Section 3		
State	County	Waste	Degree of	Receiving
	Industry	MGD	Treatment	Stream
Pennsylvania				
Bucks				
	U.S. Steel Corp.	73.9	Secondary	Delaware Estuary
	J.A. Roebling & Sons	15.3	None	Delaware Estuary
	Paterson Parchment Co.	1.7	Secondary	Delaware Estuary
	Superior Zinc Co.	0.2	Secondary	Delaware Estuary
	Purex Corp. Ltd.	1.7	None*	Delaware Estuary
	Hercules Powder Co.	0.1	Secondary	Delaware Estuary
	Rohm & Haas Co.	5.0	Secondary	Delaware Estuary
	Pennsalt Chemical Corp.	0.1	None*	Delaware Estuary
Philadelphia				
	Allied Chemical Corp.	0.0	None*	Delaware Estuary
	Rohm & Haas Co.	5.0	None*	Delaware Estuary
	Penn Sugar Div. - Nat.			
	Sugar Refining Co.	2.5	None*	Delaware Estuary
	Publicker Industries Inc.	5.8	None*	Delaware Estuary
	U. S. Navy Base	1.4	None*	Delaware Estuary
	Gulf Oil Co.	12.5	Primary	Schuylkill River
	Atlantic Refining Co.	24.6	Secondary	Schuylkill River
	U. S. Gypsum	2.2	Primary	Schuylkill River
	Boeing Vertol Div.	0.1	Primary	Crum Creek
Delaware				
	Scott Paper Co.			
	Foam Cont. Div.	0.2	None**	Delaware Estuary
	Scott Paper Co.	13.5	Primary	Delaware Estuary
	Penn Ind. Chemical Corp.	0.2	Primary	Delaware Estuary
	Sinclair Refining Co.	59.4	Primary	Delaware Estuary
	American Viscose Corp.	1.5	Primary	Delaware Estuary
	Sun Oil Co.	103.4	Primary	Delaware Estuary
	General Chemical Div.			
	Allied Chemical Corp.	36.0	Primary	Delaware Estuary
Delaware				
New Castle				
	Phenix Steel Corp.	0.7	Primary	Naamans Creek
	Atlas Chemical Ind., Inc.	12.0	Secondary	Delaware Estuary

* Primarily Cooling Water

** Secondary Treatment Plant under construction

State County Industry	Waste MGD	Degree of Treatment	Receiving Stream
Delaware			
New Castle			
Avisum Corp.- Polymer Plant	0.3	Primary	Delaware Estuary
Tidewater Oil Co.	301.9	Primary	Delaware Estuary
New Jersey			
Burlington			
R.D. Wood Co.	1.6	None	Delaware Estuary
Cary Chemical Co.	0.7	Secondary	Delaware Estuary
U. S. Pipe & Foundry Co.	0.6	None*	Delaware Estuary
B. F. Goodrich Industries Products	0.4	None	Delaware Estuary
M. K. Porter, Inc.	0.3	Secondary	Delaware Estuary
Moeganes Sponge Iron Co.	0.1	None*	Delaware Estuary
Camden			
U. S. Steel Prod. Div.	0.1	None	Pennsauken Creek
Georgia Pacific Corp.	2.0	None	Delaware Estuary
MacAndrews & Forbes Co.	4.3	Primary	Delaware Estuary
The Ruberoid Co.	0.1	Primary	Delaware Estuary
New Jersey Zinc Co.	4.7	None	Delaware Estuary
Gloucester			
Texaco, Inc.	2.5	Primary	Delaware Estuary
Shell Chemical Co.	2.0	Secondary	Delaware Estuary
Mobil Oil Co.	34.6	Primary	Delaware Estuary
Hercules Powder Co.	0.3	Primary	Delaware Estuary
E.I. DuPont-Repauno Works	52.3	Primary	Delaware Estuary
Salem			
Monsanto Chemical Co.	1.2	None	Delaware Estuary
E.I. DuPont-Carneys Point Works	5.0	None	Delaware Estuary
E.I. DuPont-Chambers Works	104.8	Primary	Delaware Estuary

* Primarily Cooling Water

NOTE: In many installations inplant waste reduction is practiced which is not necessarily reflected in the degree of treatment column.

IX-3

